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SYSTEM DESCRIPTION - AVIATION WIDE-ANGLE VISUAL SYSTEM (AWAVS) --ETC(U)
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: 18 19 NAVTRAEQUIPCE[redacted]/76-C-0048-1
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): 6 System Description - Aviation Wide-Angle Visual System (AWAVS) Computer Image Generator (CIG) Visual System.
5. TYPE OF REPORT & PERIOD COVERED: 9 Final Rep[redacted]t.
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 D. V. Morland
8. CONTRACT OR GRANT NUMBER(s): 15 N61339-76-C-0048
9. PERFORMING ORGANIZATION NAME AND ADDRESS: General Electric Company, Space Division, P.O. Box 2500, Daytona Beach, Florida 32015
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NAVTRAEQUIPCEN Task No. 4781
11. CONTROLLING OFFICE NAME AND ADDRESS: Commanding Officer, Naval Training Equipment Center, Orlando, Florida 32813
12. REPORT DATE: 11 Feb[redacted]79
13. NUMBER OF PAGES: 82
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 86p.
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computer Image Generation
Flight Simulator Visual Display

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides an overall description of the Aviation Wide Angle Visual System (AWAVS) Computer Image Generator (CIG) System installed at the Naval Training Equipment Center in Orlando, Florida. The report includes descriptions of system functions and capabilities, system hardware and new technology features incorporated in the CIG System design.

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SECTION I

GENERAL DESCRIPTION

GENERAL

The Aviation Wide Angle Visual System (AWAVS) Computer Image Generator (CIG) System was designed and manufactured by the General Electric Company Space Division Ground Systems Dapartment under Naval Training Equipment Center Contract N61339-76-C-0048. The system is integrated with the AWAVS flight simulator research tool and display system to provide the following functions:

a. Real-time, monochrome television raster displays of simulated flight environment scenes.

b. Nonreal-time production of simulated flight environment scene still and motion picture films.

c. Capability for constructing software data bases for environment scenes.

SYSTEM DESCRIPTION

GENERAL. The AWAVS CIG Visual System is composed of two subsystems: Image Generation and Data Base Development Facility. Principal elements of the two subsystems are identified in figure 1.

The Image Generation Subsystem processes stored environment data for a given geographical region and produces true-perspective visual scenes of the environment as it would be viewed from the cockpit of an aircraft flying through the environment.

The Data Base Generation Facility provides capabilities for developing, modifying and photographically recording visual scene data bases to be processed by the Image Generation subsystem.

IMAGE GENERATION SUBSYSTEM. Real-time visual scenes of a simulated flight environment are generated as a function of environment data input to the general-purpose computer from magnetic disk storage and flight dynamics data provided by the AWAVS flight simulator computer. The environment data base contains model, object and surface feature data for a given gaming area which is stored in numerical form on the magnetic disk. The data received from the AWAVS flight simulation computer includes viewpoint aircraft position and orientation with respect to the environmental coordinate system. The general-purpose computer transfers environment, position and attitude data to the image processor for video scene processing. The image processor processes the environment data to form a true perspective, two-dimensional scene of the data and converts the scene data to a television raster line display format for display on the AWAVS display screen and two television monitors at the

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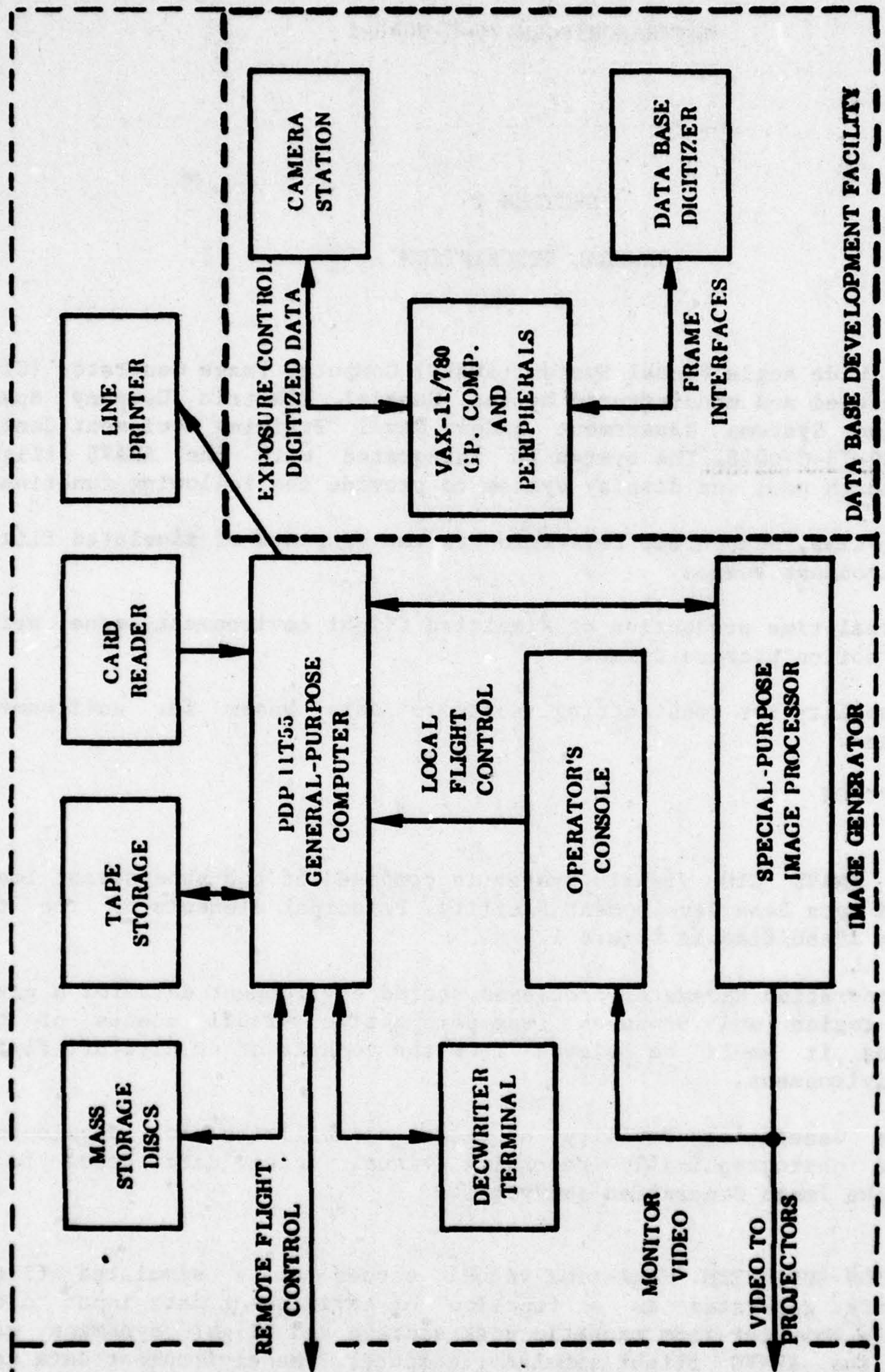

Figure 1. AWAVS System Functional Block Diagram

operator's console. The video scene is updated at a 1/60-second field rate to create the illusion of continuous motion through the environment. Overall characteristics of the Image Generation subsystem are listed in table 1.

Off-line maintenance diagnostic operation of the Image Generation subsystem is implemented via a dialog between the operator at the DECwriter and diagnostic test software programs executed by the general-purpose computer. The diagnostic test software programs are designed to fully exercise functions of the image processor and provide error messages at the DECwriter terminal. The software programs are stored on a single magnetic disk and are transferred to the general-purpose computer core memory when called by user inputs at the DECwriter terminal.

The operator's console and a DECwriter terminal provide operator interface for on-line, off-line and maintenance operations monitoring of AWAVS CIG system operation. The console contains two monochrome CRT monitors and a joystick control. The two CRT monitors display the two-channels of visual source data generated by the Image Generation subsystem. The joystick enables the operator to maneuver the viewpoint throughout the CIG environment in a stand-alone mode. The DECwriter terminal enables the operator to interact with on-line or off-line software programs by means of a teletype dialog. For off-line operations, the operator may perform data base maintenance functions and execute diagnostic test routines.

TABLE 1. IMAGE GENERATION SUBSYSTEM CHARACTERISTICS

Color	Black and White
Gaming Area	345 Nautical Mile x 345 Nautical Mile
On-Line Data Base Storage	10,000 Edges and 4000 Point Lights
Lighting Options	Daylight, Dusk, Dark
Potentially Visible Edges	2048 Edges
Variable Size Light Sources	2048 (Expandable to 4096)
Directional Lights	Yes
Scene Update Rate	30 Hz (two viewpoints) 60 Hz (one viewpoint)
Total Resolution Parameters	525, 825, 1023 Lines/Frame 635, 1010, 1303 Elements/Line
Displayed Resolution	499, 784, 972 Active Lines/Frame 524, 823, 1021 Active Elements/Line
Maximum Edge Crossings/Raster Line-System-Commensurate with Video	500, 300, 250 Edge Crossings
Levels of Detail	
Model/Object	8
Face	8 (Continuous from 0 to 100%)
Moving Models (30 Hz Update)	6
Total Objects per Scene	256 Objects (112 3D objects + 2D objects up to maximum number of faces)
Edge Faces per Scene	512
Light Faces per Scene	512
Face Blending	Yes
Curved Surface Shading	Yes
Digital Edge Smoothing	Yes
Variable Fog/Fading	Yes
Aerial Perspective	Yes

Movable Clouds (Penetration and Breakout)	Yes
Two-Viewpoint Capability	Yes
On-Line Data Base Update	Yes
Collision Detection	Yes
Horizontal Keystone Distortion Correction	Yes
Programmable Point Light Size	Yes
Gray Shades (Color Hues with Expanded System)	
- Lights	256
- Models	256
Gray Shade Resolution	256:1
Channels - Implemented	2
- Growth	5
Field of View (Horizontal and Vertical)	Each Channel Independently Variable
Computer Aided Diagnostics	Yes
Built-in Test Hardware	Yes

DATA BASE GENERATION FACILITY. The Data Base Generation Facility is used to perform two basic functions: development and modification of environment data bases for the Image Generation subsystem and the production of still and motion picture films of simulated environment scenes.

Data base development and modification is accomplished by means of the digitizer station and data base development software programs executed by the VAX 11/780 computer. The digitizer station includes a digitizer tablet and a CRT monitor console with an ASCII keyboard. The digitizer tablet is equipped with electronic pens whereby the operator can "draw" objects and models for inclusion in a data base. The objects and models drawn on the tablet are digitized and can be displayed on the CRT monitor in various orientations for operator verification. As a function of the dialog between the operator and data base generation software program, new data base objects and models can be positioned within an environment scene and stored as an element of an environment data base. Objects and models from a data base previously created at the Data Base Generation Facility can likewise be displayed at the CRT monitor and subsequently changed by correction data entered via the digitizer tablet. Overall data base generation hardware and software characteristics are summarized in table 2.

Nonreal-time production of environmental scene still or motion picture films is accomplished by means of the camera station and software programs executed by the VAX 11/780 computer to simulate image processor hardware functions. The

camera station consists of a high-resolution cathode-ray tube and its associated control circuitry, a polaroid still camera and a 35mm movie camera. The camera station display and control software transfers environment data to the camera station, controls operation of the polaroid and 35mm cameras and provides a teletype dialog for user control of viewpoint parameters. The camera station display and control program also provides for operator modification of environment data via a data entry console. The camera station control circuitry processes the raster format data received from the VAX 11/780 computer and sequentially constructs the entire environment scene. The display resolution is adjustable between 1024 and 4096 lines per frame. Overall characteristics of the camera station are summarized in table 3.

TABLE 2. DATA BASE GENERATION CHARACTERISTICS

Tablet	
Size	34 x 44 Inches
Accuracy	± 0.003 Inch
Repeatability	± 0.003 Inch
Linearity	± 0.006 Inch
Repetition Rate	400 Coordinate Pairs/Second
Graphic Display	
Type	Storage CRT
Number Display Points	1024 x 1024
Display Size	19-Inch Diagonal
Storage Time	15 Minutes
Luminance	5 Footlamberts Minimum
Keyboard	ASCII Characters (96)
Hard Copy	Yes
Interactive	Yes
View Modification	Rotate Translate Any Axis Stretch Shrink
Model Book Provisions	Yes

TABLE 3. CAMERA STATION SUBSYSTEM CHARACTERISTICS

Plotting Matrix - Low Resolution	1024 x 1024 Picture Elements
- Medium Resolution	2048 x 2048 Picture Elements
- High Resolution	4096 x 4096
Variable Resolution	
- Full Format Exposure	Integral Fractions of Above
- Reduced Format Exposure	Any Non-Integral Values of Above
Film Format	100 Feet, 35mm Magazine Polaroid Film Holder Model 405
Exposure Levels	256
Exposure Range	Extrachrome 6115 - 2.0D Plus X Plan 4147 - 1.8D
Exposure Uniformity	$\pm$0.35D Maximum
Exposure Control	Yes
Hardware Recording Speed	
- Black/White	5.5 Min (Nominal Maximum Time for
- Color	16.5 Min High Resolution)
Interface Signals	Data Control Commands Recorder Status Codes
CIG Simulation	Raster Scan
Data Base	Common with Real-Time CIG
Scene Content Statistics	Yes
Predetermined Flight Path Processing	Yes
Simulation of Real-Time CIG	Yes - Nonreal Time

REAL-TIME CIG. During real-time operation of the Image Generation subsystem, the subsystem calculates a new scene for each television raster field. Each new scene is based on updated viewpoint position and orientation values derived from position and orientation data received from the AWAVS system computer. Major functional elements of the subsystem are shown in figure 2.

The Image Generation subsystem receives simulator aircraft and moving model data from the AWAVS simulator computer at a 30-Hz raster frame rate. This data includes simulator aircraft position and attitude, moving model position and attitude, environment control data (fog, cloud parameters, etc.) and discrete control functions.

To compute the visual scene, three major processing cycles run concurrently in the Image Generation subsystem, one in the general-purpose computer and two in the Image processor. The cycles are termed Frame I, Frame II and Frame III. These terms also identify the three functional subdivisions of the Image Generator subsystem that perform the processing cycles. Data for a given television raster field is processed sequentially through each computation cycle. Each processing cycle is repeated every 1/60-second to provide a television raster display that is updated every 1/60-second.

The pilot's viewpoint position and orientation within the three dimensional operating area is calculated by extrapolating the simulated attitude and position data to match the 60-Hz processing rate. Similarly, the position and orientation of any pertinent moving models (such as an aircraft carrier) is calculated followed by the special processing required for the Fresnel Lens Optical Landing System (FLOLS).

Subsequent to establishing the viewpoint position and orientation for the scene to be generated, the general-purpose computer calculates the factors required for the Frame II and Frame III fading computations. The fading factors are derived from the viewpoint position and orientation with respect to the environment, and the fog/visibility characteristics entered by the operator. Point lights are also controlled by programmable intensity/range curves.

At the end of the Frame I computation cycle, the output data (viewpoint and moving models position and orientation, fading factors, etc.) are transferred to the image processor hardware.

During the Frame II operation cycle, a two-dimensional image of the environment is computed for the current viewpoint position and attitude. Each model within the viewable area of the environment is identified and its appropriate level-of-detail selected. Then, the faces for the selected level-of-detail of each of these models are processed for visibility in each display channel. The edges and lights associated with each visible face are projected in true perspective to the view plane of each display channel. The color for each face of a nonsurface object or for a light are adjusted for the correct fog/visibility conditions. The Frame II operation also creates a face priority list that identifies the priority relationship of each active visible face with respect to the other active faces. The two-dimesional image data for the edges and point lights, and the face priority list are output to the Frame III functions at the completion of the Frame II cycle.

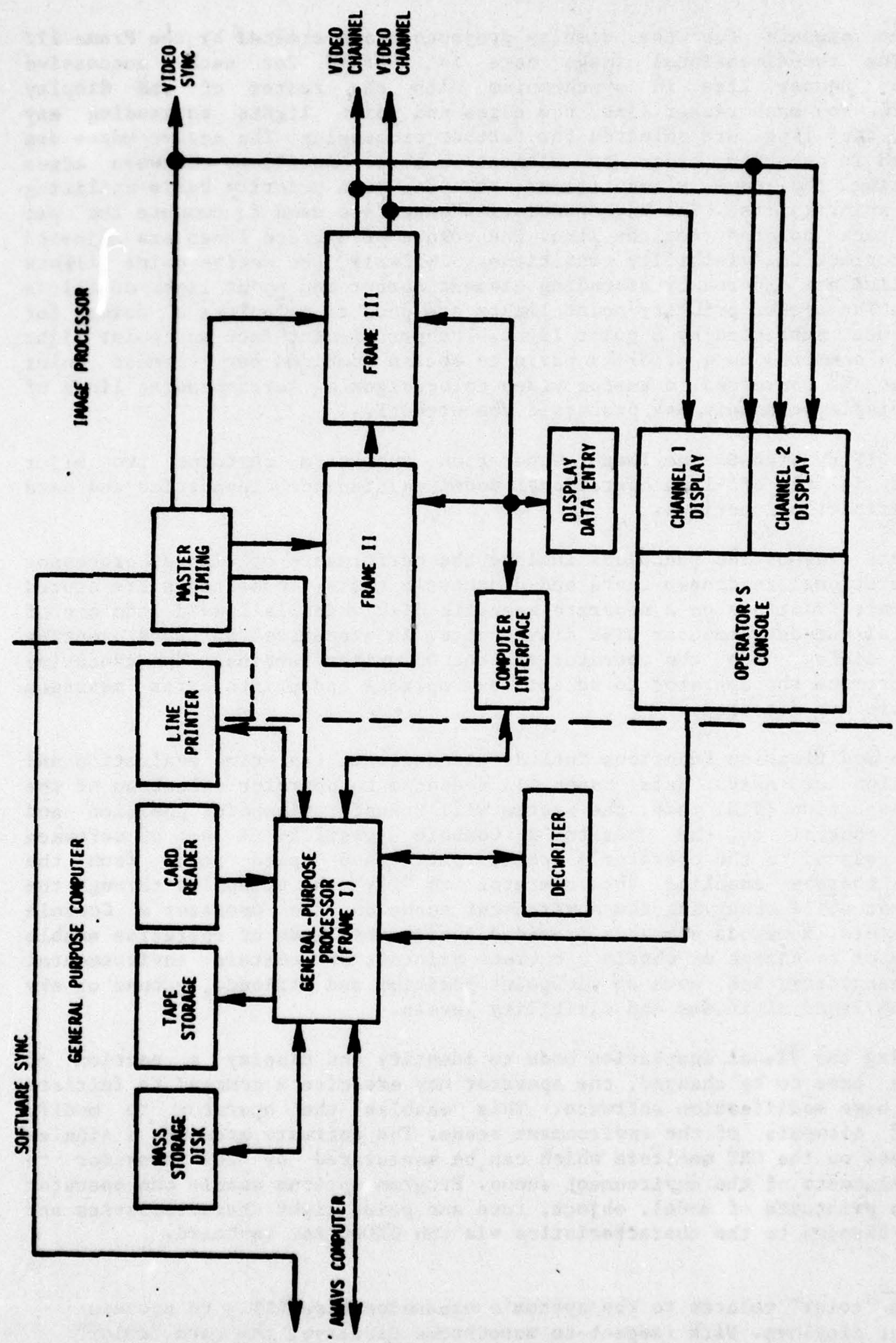

Figure 2. Image Generation Subsystem Block Diagram

The video signals for the display projectors are created by the Frame III cycle. The two-dimensional image data is scanned for each successive television raster line in synchronism with the raster of the display projectors. For each raster line, the edges and point lights subtending any part of the line are selected for further processing. The active edges are structured in ascending order by element number. Conflicts between edges intercepting the same element(s) are resolved on a priority basis utilizing the face priority list. The higher priority edges are used to compute the per element face colors* for the line. The colors of surface faces are adjusted for the correct fog/visibility conditions. Similarly, the active point lights for a line are ordered by ascending element number and point light conflicts resolved. The higher priority point lights are used to calculate a color for each element subtended by a point light. The per element face and point light colors are combined on a priority basis to obtain combined per element color data that is converted to analog video color signals. Corresponding lines of the two display channels are processed concurrently.

OFF-LINE CIG FUNCTIONS. The Image Generation subsystem performs two major functions in the off-line operational mode: maintenance diagnostics and data base modification functions.

Maintenance diagnostics functions include the performance of image processor daily operational readiness tests and diagnostic tests. These tests are stored as software routines on a separate magnetic disk which is loaded into one of the general-purpose computer disk drive units. An executive software routine provides dialog with the operator via the DECwriter terminal. The executive routine prompts the operator to select test options and prints error messages when errors are detected.

Data base modification functions include stand-alone, real-time evaluation and modification of AWAVS data bases. In response to operator selection of the Visual Inspection (VIN) mode, the system will transfer viewpoint position and attitude control to the Operator's Console joystick. A set of software dynamics respond to the operator's roll, pitch and speed input from the joystick thereby enabling the operator to "fly" the viewpoint through the environment while observing the environment scene on the Operator's Console CRT monitors. Numerous commands provided during this mode of operation enable the operator to change or obtain a current printout of certain environmental scene characteristics such as viewpoint position and attitude, ground or sky color, fog layer altitudes and visibility levels.

After using the Visual Inspection mode to identify and display a section of the data base to be changed, the operator may exercise a command to initiate the data base modification software. This enables the operator to modify displayed elements of the environment scene. The software presents a single-line cursor on the CRT monitors which can be maneuvered by the operator to select elements of the environment scene. Program options enable the operator to obtain printouts of model, object, face and point light characteristics and to enter changes to the characteristics via the DECwriter keyboard.

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*The term "color" relates to the system's expansion capability to process full color displays. With respect to monochrome displays, the term "color" relates to the intensity level or "shade of gray" value assigned to faces, point lights, sky, ground and fog.

SECTION II

SUBSYSTEM EQUIPMENT DESCRIPTION

GENERAL

This section provides individual descriptions of the major equipment items that comprise the AWAVS CIG Visual System.

GENERAL-PURPOSE COMPUTER

EQUIPMENT DESCRIPTION

The general-purpose computer used in the AWAVS CIG Image Generation Subsystem is a PDP-11/T55 16-bit word, general-purpose digital computer and associated peripherals manufactured by the Digital Equipment Corporation. The functional configuration of the hardware is shown in figure 3 and includes the following equipments:

1. PDP-11/T55 general-purpose computer including:

    a. KB11-D 16-bit processor
    b. KT11-CO memory management unit
    c. KW-L line frequency real-time clock
    d. MS11-AP 32K word bipolar point memory
    e. MS11-CC bipolar memory controls
    f. BM873-YB multipurpose bootstrap loader
    g. FP-11-C floating point processor
    h. MF-11-UR 32K parity core memory

2. TMB11-EA 9-track magnetic tape transport and control unit

3. RK05J-AA moving head disk drive and RK11J-DE 1.2 million-word disk unit

4. CR11 300 cards/minute punched card reader and control unit

5. ADK11-KT real-time analog data acquisition system and programmable clock.

6. LP11-VA line printer and control unit

7. DR11-B general-purpose direct memory access interface units (3)

8. DR11-C general-purpose digital interface unit

General-purpose computer characteristics are summarized in table 4.

The Central Processing Unit (CPU), memory and peripherals are interconnected by and communicate via a common bidirectional bus identified as the UNIBUS. The bus provides bidirectional and asynchronous communications wherein devices can send, receive, and exchange data without interrupting the basic computational cycles of the CPU.

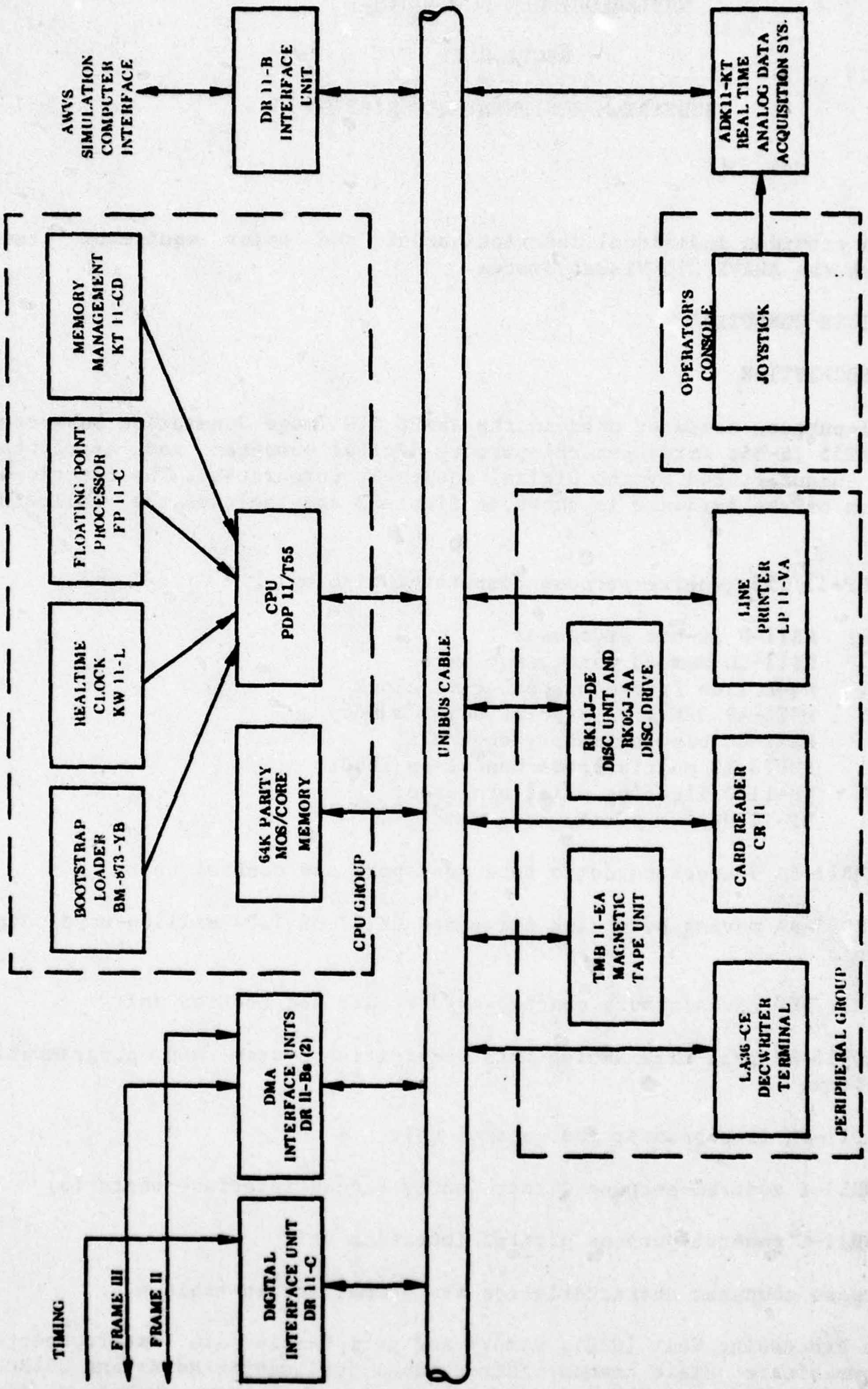


Figure 3. AWAVS-CIG System Computer System Equipment Organization

TABLE 4. GENERAL-PURPOSE PROCESSOR CHARACTERISTICS

Manufacturer/Model	DEC PDP-11/T55
Operating System	QJ620-AE
Active Memory	64K Words
Clocks	2 Programmable, 1-Line Frequency
Processor	Floating Point, Hardware Multiply/Divide
Loader	Bootstrap
Power Fail and Restart	Yes
Mass Storage	
Moving Head Disc	1.2M Word-70 ms Access
Tape	9 Track, 45 IPS, 800-bits/inch
Line Printer	300 LPM, 132 Columns
Card Reader	EIA Standard 80 Column Cards, 285 cpm
DECwriter Terminal	30 Characters/Seconds
Interface	Direct Memory Access
I/O Channels	20 Devices
I/O Spare	40 Percent
Expansion Capability	
Memory	64K to 128K Words
Memory Cycle Time	980 Nanoseconds to 300 Nanoseconds
Mass Storage	
Moving Head Discs	1.2M to 9.6M Words
Tape	1 Drive to 8 Drives
Card Reader	285 cpm to 1200 cpm
Line Printer	1200 lpm to 3000 lpm

CENTRAL PROCESSOR UNIT

Elements of the central processor unit (CPU) equipment group reside in two cabinets; a basic H-960 cabinet and an expansion H-960D cabinet. The KB11-D CPU contains data manipulation elements, a bus register, general registers and special registers. The data manipulation elements perform arithmetic, logic and shift operations on data received from various sources. The bus register is the input/output register for all data input to or output from the data manipulation elements. The general registers also interface with the data manipulation elements and provide primary storage for data and address constants.

The FP11-C floating point processor is an integral part of the CPU equipment group and provides an instruction set for performing single and double precision floating point arithmetic operations.

The MS11-AP 32K-word bipolar parity memory and the MF11-UR 32K-word parity core memory provide a total CPU parity memory capacity of 64K words. Memory management is provided by the KT11-CD memory management unit.

The KW11-L line time clock provides 16 2/3 msec timing reference.

The BM873-YB bootstrap loader permits quick loading of bootstrap programs or restarts of PDP 11/T55 programs from peripherals.

PERIPHERALS

The TMB11-EA magnetic tape unit provides backup capability for storing large volumes of data and programs. The unit handles 9-channel, 800-BPI tapes. Each 10 1/2-inch tape reel provides storage capability for over 180 million data bits.

The RK05J-AA disk drive and RK11J-DE disk units provide mass storage for random access operational data bases and maintenance and diagnostic data bases. Each disk unit provides storage for over 1.2 million 16-bit words with an average word transfer time of 11.1 μ seconds. Average total access time for each disk drive is 70 milliseconds.

The CR11 card reader reads EIA standard 80-column punched card data at the rate of 300 cards per minutes. The card reader is the principal input device for source language program inputs and data base update inputs.

The LP11-VA line printer is the output device for assembler, compiler and loader listings and special data base maintenance and diagnostic test data printouts. The printer provides 64-characters, 132-column print lines and prints at 300 lines per minute.

The LA36-EE DECwriter terminal is the primary input device for system operator interaction with the real-time system software main program and the off-line diagnostic test and maintenance programs. The terminal provides an ASCII keyboard with 64 characters and prints 132-column data at 30 characters per second.

The DR11-B direct memory access (DMA) interface units are general-purpose interface devices for interfacing external devices to the UNIBUS. The DR11-B provides the user device direct access to CPU memory and executes data transfers between the user device and memory without requiring program controlled data transfer operations. As shown in figure 3, DR11-B's are used to interface the AWAVS system computer and the image processor to the general-purpose computer.

The DR11-C is a general-purpose interface device for interfacing a peripheral device to the general-purpose computer UNIBUS. The DR11-C provides logic and buffer registers for program controlled parallel transfers of 16-bit data between the general-purpose computer and the interfacing peripheral. As shown in figure 3, the DR11-C is used to input television raster timing and synchronizing signals to the general-purpose computer from the image processor.

The ADK11-KT real-time analog data acquisition system shown in figure 3 is used to interface the Operator's Console joystick control data with the unibus. The ADK11-KT converts the joystick analog outputs to equivalent digital values and provides 2 programmable real-time clocks.

SOFTWARE DESCRIPTION

The AWAVS Image Generation subsystem operates under control of the software system resident in the general-purpose computer core memory. As shown in figure 4, three software systems are provided; real-time simulation software, off-line data base creation software, maintenance/diagnostic software. Each of

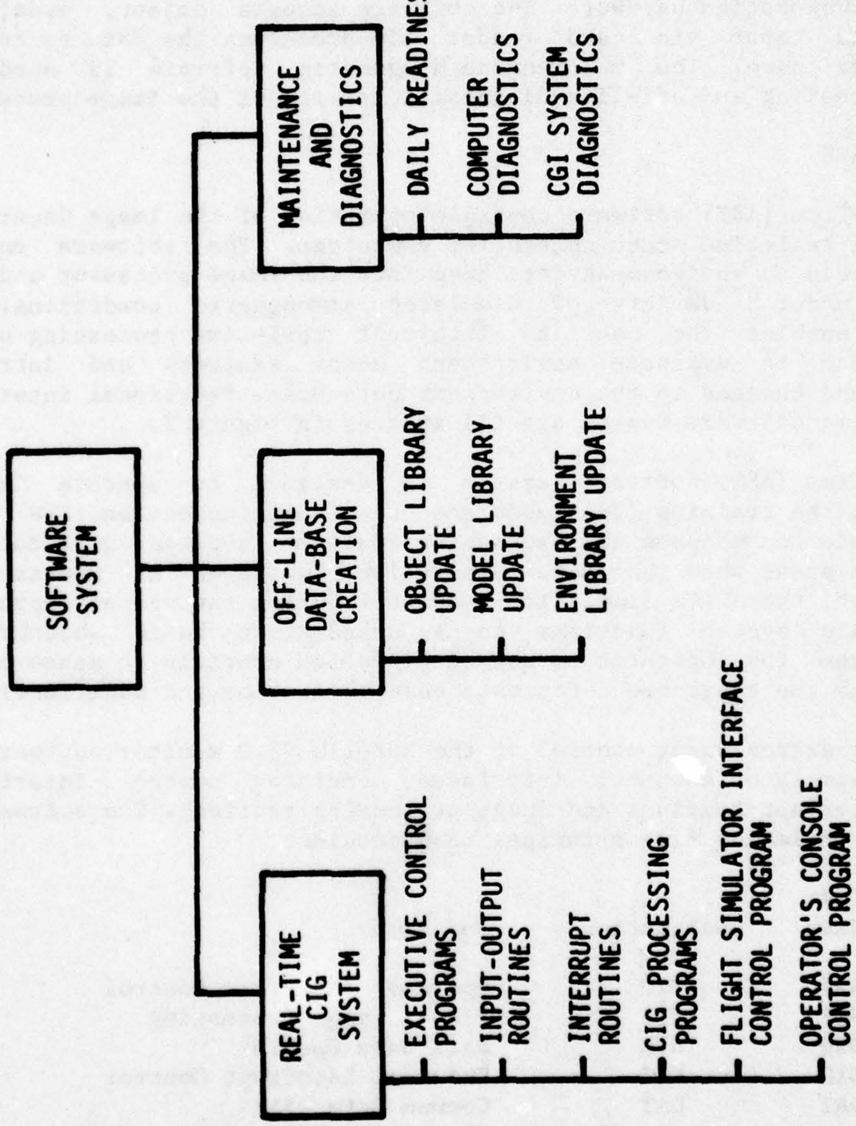


Figure 4. Image Generation Subsystem Software

these systems is stored on a separate magnetic disk. The disk is loaded into the general-purpose computer disk unit and the software is loaded into core memory in accordance with operator commands. The real-time simulation software controls image generation operations during real-time scene generation exercises and contains stand-alone programs for operator interactive modification of the real-time data base. The off-line data base creation software enables the user to define characteristics of the data base without using the Image Generation hardware. The software accepts object, model and environment data input via card reader and processes the data to form an environment data base. The maintenance/diagnostic software is used for preoperational testing and off-line diagnostic testing of the image processor.

REAL-TIME SOFTWARE

The AWAVS Real-Time (ART) software controls operation of the Image Generation Subsystem during real-time scene generation exercises. The software enables the user to load an environment data base into the image processor and view the environment under a variety of simulated atmospheric conditions. The software also enables the user to interrupt real-time processing of the environment scene to evaluate environment scene features and introduce modifications and changes to the environment data base. Functional interfaces with the real-time software system are illustrated in figure 5.

The AWAVS Real-Time (ART) software system is designed to operate in two principal modes; the training (TRA) mode and the visual inspection (VIN) mode. The training mode encompasses all processing routines involved in producing a real-time visual scene when the Image Generation Subsystem is operated in conjunction with the AWAVS simulation computer. During the visual inspection mode, the software system functions on a stand-alone basis whereby the operator can use the Operator's Console joystick controls to maneuver the viewpoint through the environment for data base evaluation and modification.

The ART system operates under control of the RSX-11M V3.0 monitor software and controls AWAVS simulator computer interfaces, operator control interfaces, input/output interrupt routines and image processing routines. The software is composed of the following five principal task modules:

Task Name	Designation	Function
ART	OIC	Operator Interface Control
VIP	VIP	Visual Image Processing
DBU	DVU	Data Base Update
EIC	EIC	External Interrupt Control
DAT	DAT	Common Data Task (Common to first four tasks)

The first four tasks are ranked according to processing priority and operate under individual functional executive programs. The DAT task is a common task module shared by the ART, VIP, DBU, and EIC tasks. The hierarchial arrangement of the real-time software is illustrated in figure 6. This hierarchial multitask structure enables the system to handle transient worst-case processing loads without sacrificing image continuity. The priority arrangement is such that lower priority tasks will be delayed to provide additional processing time for the visual image processing task and external interrupt routines as required.

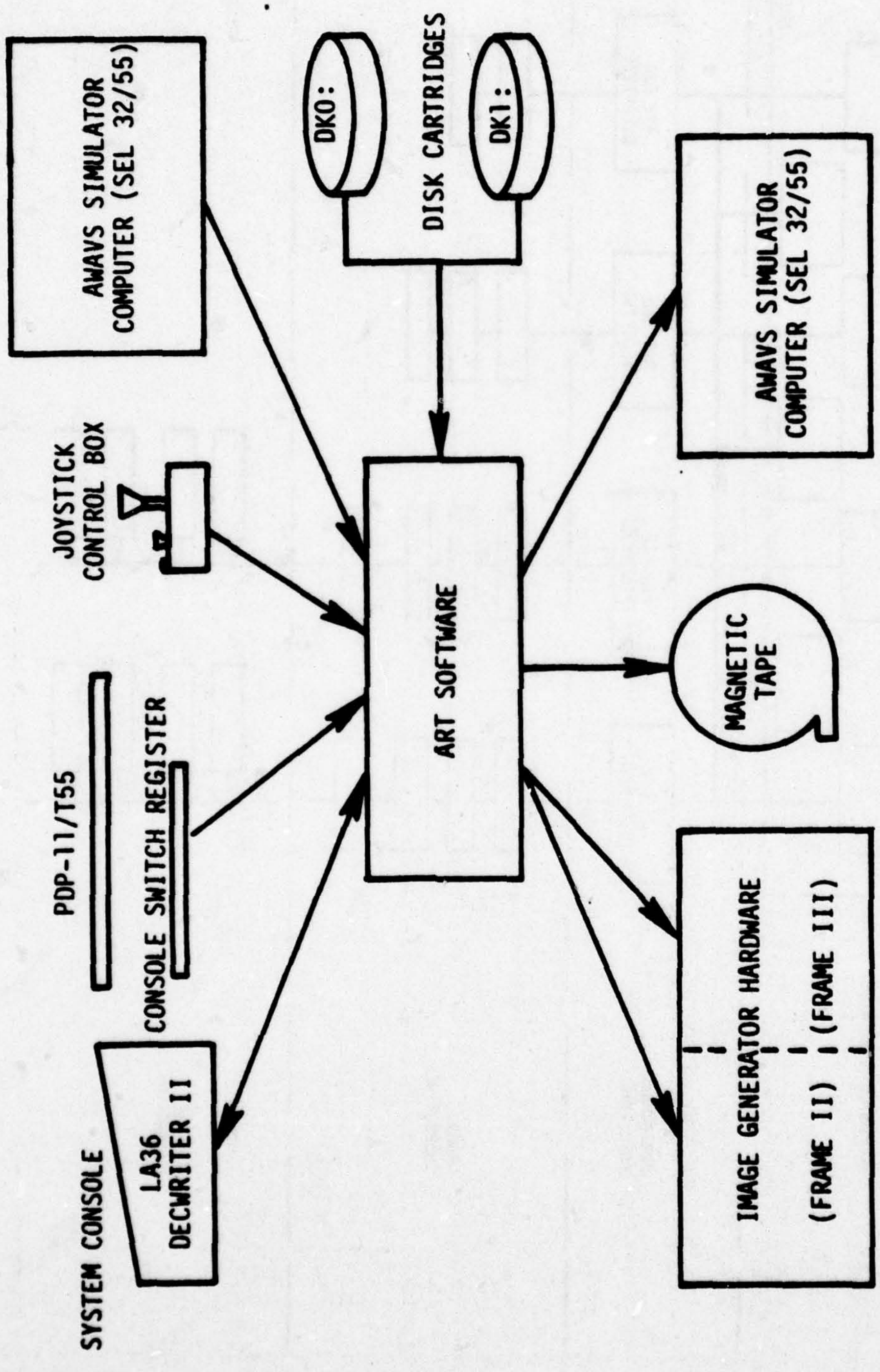


Figure 5. Real-Time Software System Interface

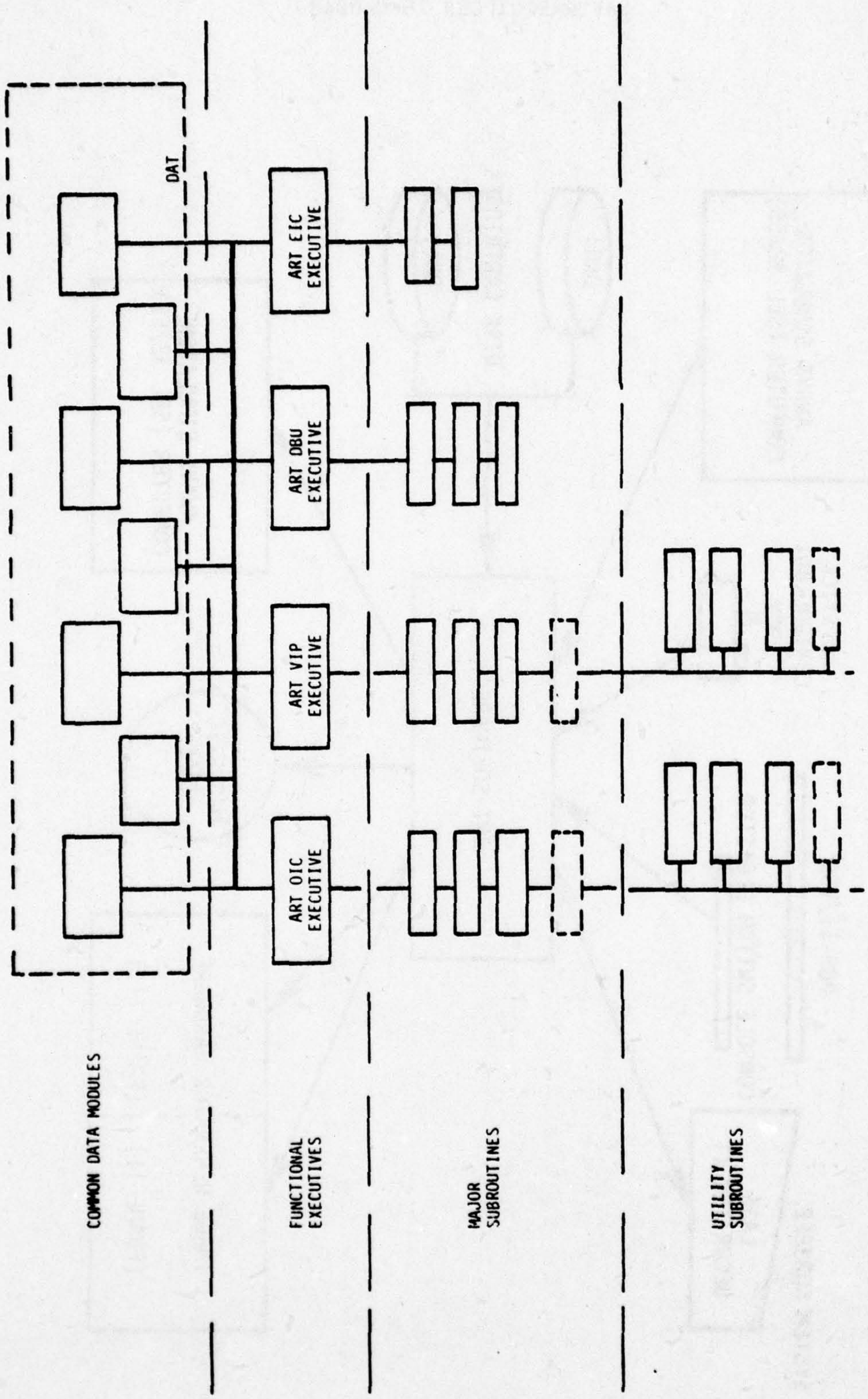


Figure 6. AWAVS Real-Time Software System Organization

The operator interface control (OIC) module initiates the EIC, VIP, and DBU modules upon system initialization and processes operator inputs via the Operator's Console DECwriter and general-purpose computer console switch register. The visual image processing (VIP) module controls all real-time image processing routines. The external interrupt control (EIC) module controls data transfers between the general-purpose computer and the image processor and between the general-purpose computer and AWAVS simulation computer. The data base update (DBU) module contains all processing routines involved in transferring environment data base data from the magnetic disks to the Image Generation hardware.

Once initialized, the ART system provides the operator with a variety of command options which can be input via the operator console Decwriter keyboard. The following is a representative summary of the operational options the operator can effect by means of these commands:

a. Load and execute real-time display of an environment data base.

b. Establish atmospheric conditions such as ground and sky colors, fog layers, visibility levels, sun angle, and sun illumination level.

c. Establish coordinate locations for moving models and each of two viewpoints.

d. Select one of three video scene television raster resolution rates.

e. Initiate or suspend special processing functions such as collision detection and distortion control.

f. Perform visual inspection and modification of an environment data base.

One of the operator selectable command options provided in the real-time software is the visual inspection (VIN) command which places the system in a stand-alone operational mode and transfers control of viewpoint position and attitude to the Operator's Console joystick. In this mode of operation the user may use the joystick to fly through the real-time data base while monitoring the display on the Operator's Console CRT monitors. This option provides a convenient means for examining various aspects of the real-time data base and for selecting an area of the data base for modification. If an area of the data base is to be modified, the user may select the environment update (UEM) command option which freezes the display at the area selected and transfers environment update software programs from the real-time disk to computer core memory. With the environment update software initiated, a single line cursor will appear on the CRT monitors. The cursor position is controlled by the joystick and can be positioned to point to the model, face, or point light to be modified. User dialog and command options provided by the environment update software enables the user to obtain a printout of characteristic data stored in the environment memories for the selected environment feature or to input changes to characteristic data via the DECwriter keyboard. The effect of change data inputs will be displayed at the CRT monitors. If desired, the changed environment feature data can be recorded in the environment memory in place of the original environment feature data or

it can be saved on the data base disk for subsequent recall but neither of these actions will alter the original data recorded on the magnetic disk.

Maintenance/Diagnostic Software. Diagnostic software programs provided with the AWAVS Image Processor subsystem are divided into two categories; general-purpose computer diagnostic routines supplied by the general-purpose computer vendor and diagnostic routines specifically designed for the image processor. The general-purpose computer routines are stored on magnetic disks and tapes and provide both operational readiness tests and specific hardware diagnostic test routines. Image processor diagnostic and operational test routines are stored on a single magnetic disk and operate under control of a diagnostic executive control program. Two basic types of diagnostic test routines are provided; memory tests and discrete tests. The memory test routines transmit known data patterns to specific memories to verify memory read/write capability. Discrete test routines simulate real-time data inputs to specific image processor functions, sample data outputs from the functions and compare the data outputs with predetermined compare data to verify the function's operation. Data noncomparisons produce an error message at the DECwriter to identify the nature and location of a malfunction. The diagnostic executive control program provides a teletype dialog whereby the operator can select and execute numerous test options. One of the operator selectable test options is the operational readiness test option which effectively links and sequentially performs all memory and discrete test programs to verify image processor operational readiness.

IMAGE PROCESSOR

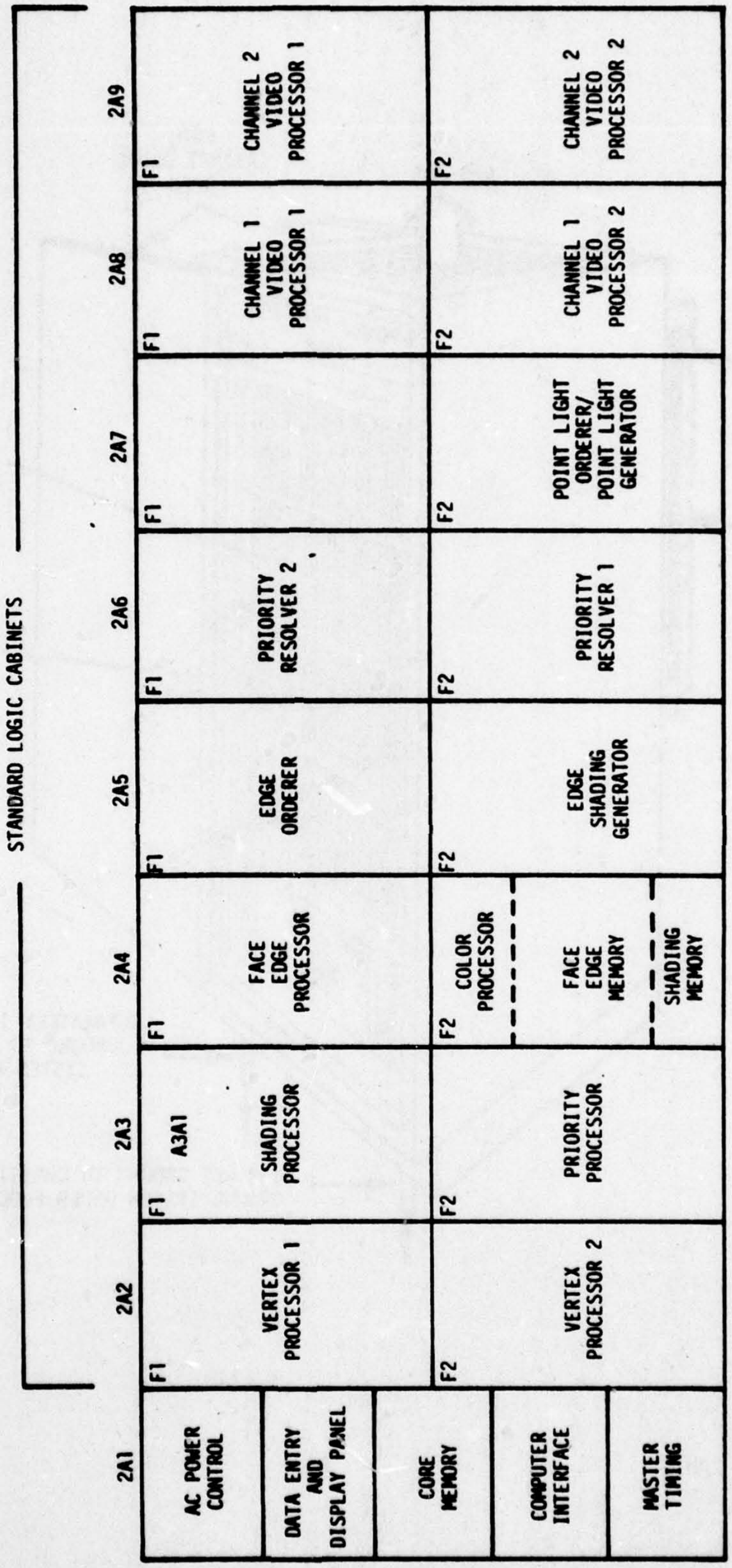
The image processor equipment performs the Frame II and Frame III operations defined in Section I. The equipment is contained in 9 logic cabinets designated as cabinets 2A1 through 2A9. Distribution of image processor functional equipment groups is illustrated in figure 7. Cabinets 2A2 through 2A9 are standard logic cabinets with front and rear swingframes for circuit card mounting. The basic configuration of these cabinets is illustrated in figure 8. Electronic and logic circuitry is packaged on 6-inch by 10-inch, plug-in edge-connector circuit boards. Each board has 140 connector pins and is mounted in a designated board slot in either the front or rear swingframes. The swingframes are hinged to the cabinet frame and can be swung outward to provide access to the rear of the circuit board connectors. Each standard logic cabinet contains a +5-VDC logic power supply, a -5-VDC power supply and a ventilation fan mounted at the base of the cabinet.

The 2A1 cabinet is a nonstandard logic cabinet which contains the environmental core memory, master timing logic, computer interface logic, the Display and Data Entry panel, and the special-purpose image processor Power Control and Monitor Panel. Figure 9 illustrates the cabinet configuration.

DATA BASE GENERATION FACILITY

EQUIPMENT DESCRIPTION

The Data Base Generation Facility is composed of three major equipment groupings; the digitizer station, the data base generation computer and the camera station. Figure 10 is a block diagram of these equipment groupings.



F1 = SWINGFRAME 1
F2 = SWINGFRAME 2

Figure 7. Physical Distribution of Image Processor Functions

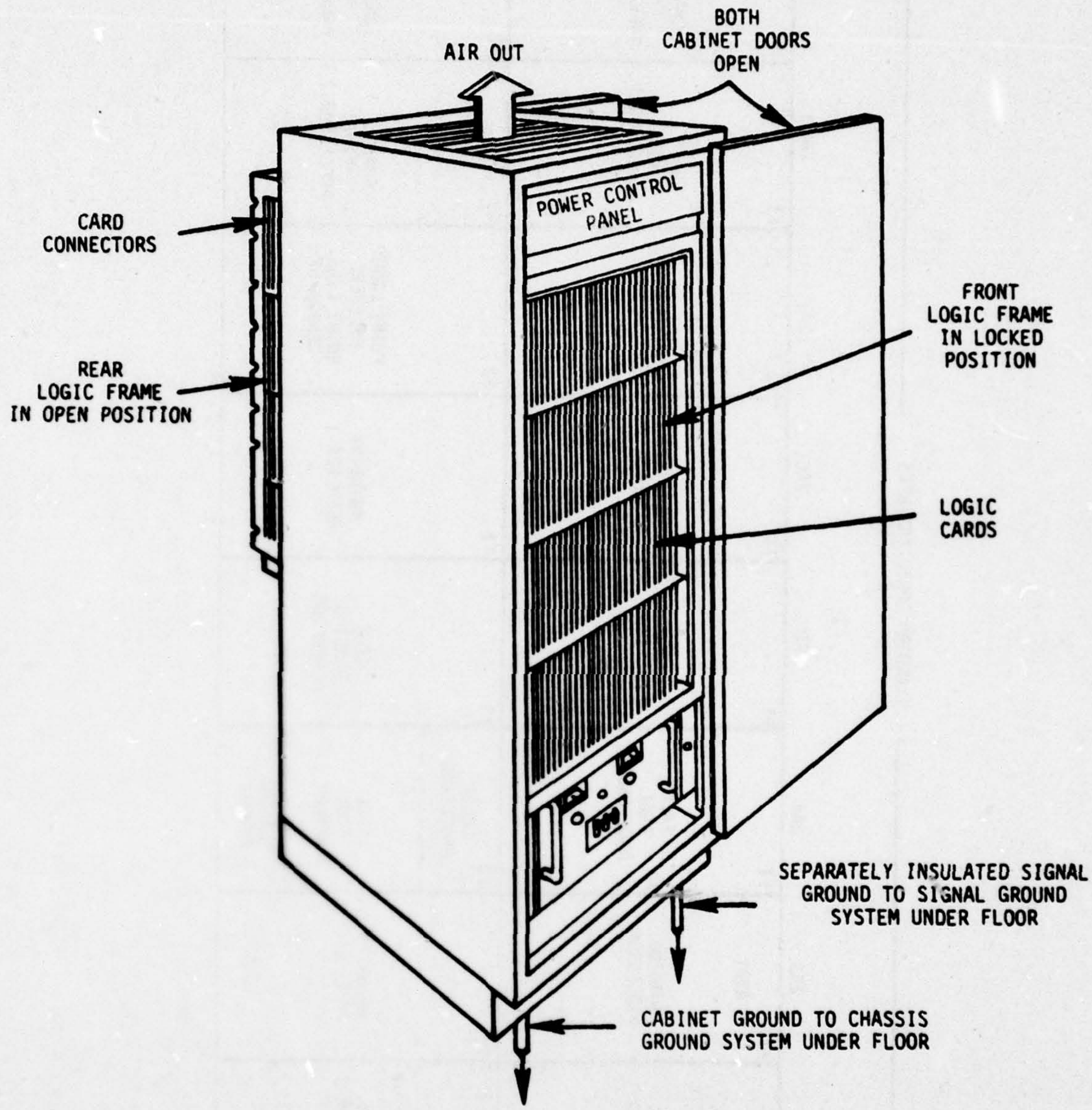


Figure 8. Typical Image Processor Cabinet Configuration

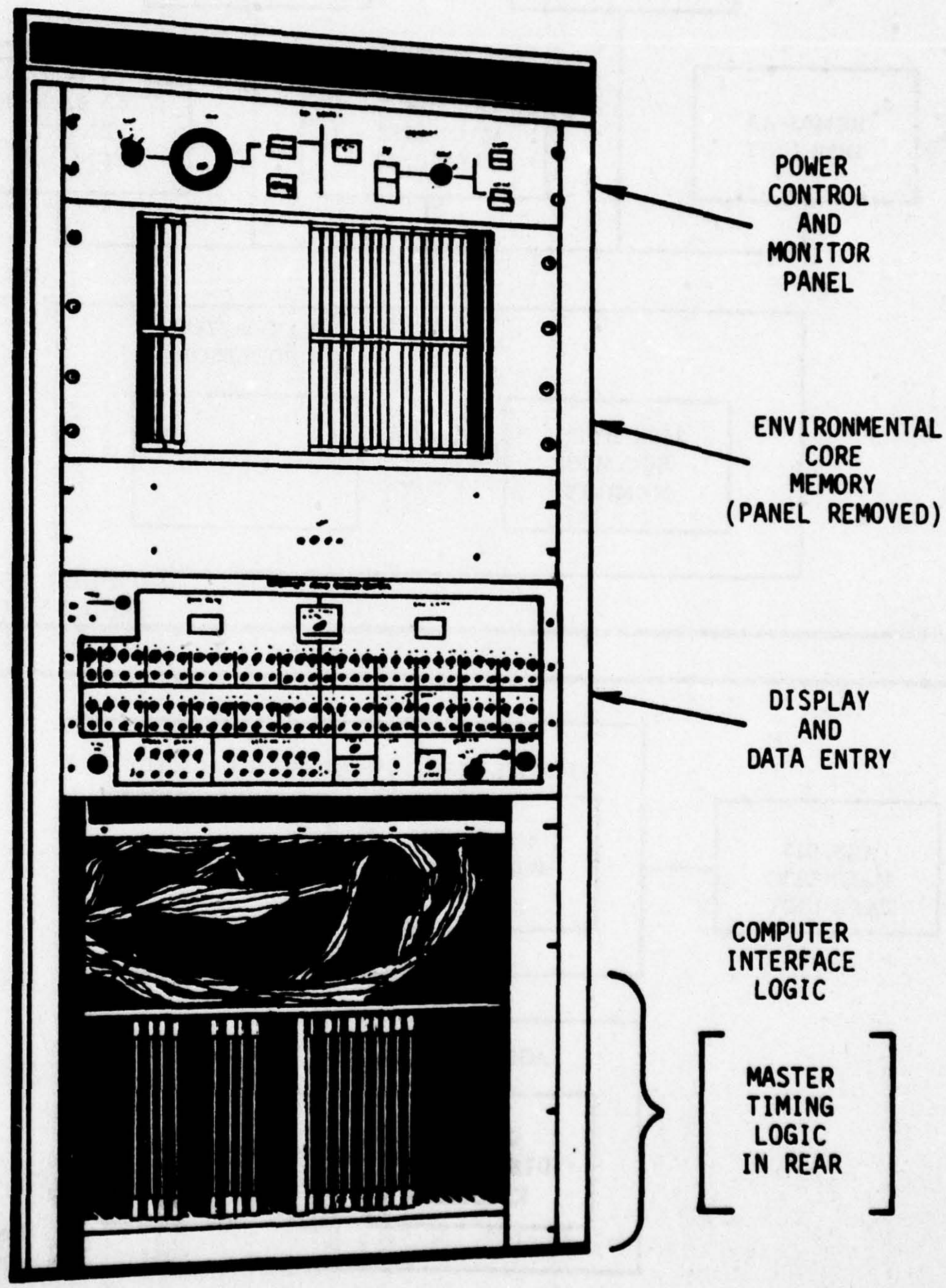


Figure 9. Cabinet 2A1 Configuration

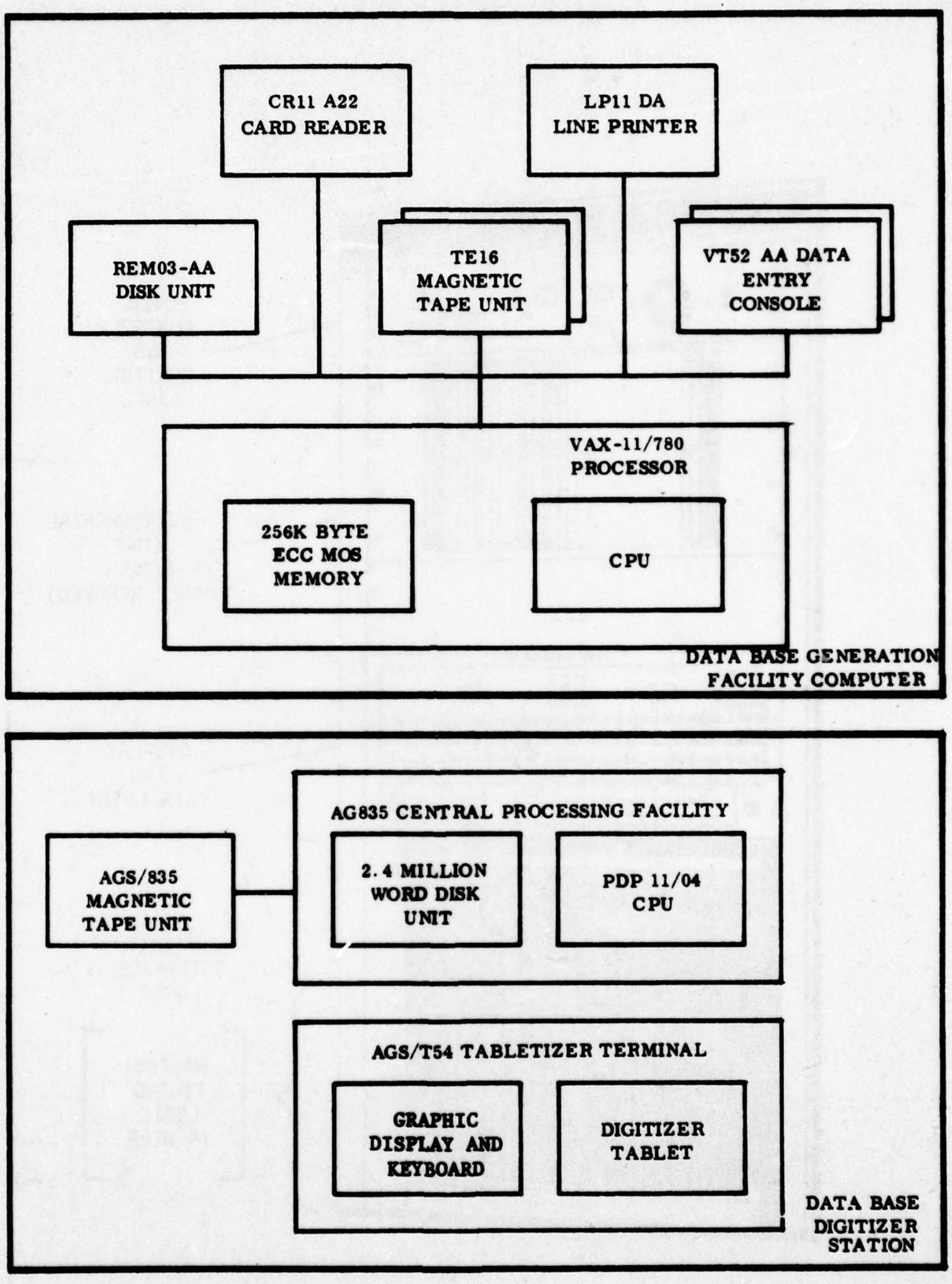


Figure 10. Data Base Generation Facility Equipment

Data Base Digitizer Station. The data base digitizer station is composed of a digitizer terminal, a central processing facility, a magnetic tape unit and a hard copy unit. The digitizer tablet consists of a 37 1/2-inch by 60-inch drafting table mounted on a rigid base with tilt and height adjustments. A 34-inch by 44-inch active digitizing area on the tablet surface is underlayed by a fine mesh wire grid of horizontal and vertical wires. Each intersection of a horizontal wire and a vertical wire defines a discrete coordinate on the digitizing surface. Two electronics pens and a high-resolution puck-type cursor are provided for marking drawing points on the digitizing area. Positioning a pen or the puck at a given point on the digitizing area identifies a drawing point coordinate to the system. Software programs implemented by the central processor establish the scaling and coordinate references for the coordinate grid in response to operator inputs. The digitizing area may be divided into four areas with independent coordinate references for digitizing three planes of a three-dimensional object. The fourth area can be used to input special operator edit and data manipulation symbols by means of the electronic pen. The 19-inch CRT graphic display provides immediate visual verification of drawing information being input and edited on the digitizer tablet. In response to operator inputs, the CRT will display orthographic, isometric or perspective views of the object and will rotate three-dimensional objects to the specified viewpoint. The CRT also displays status and error messages to cue the operator in constructing an object drawing. A 96-character ASCII keyboard position on the CRT console is used for operator inputs to annotate drawings, modify object dimensions or modify object orientation. The hard copy unit is used to produce hard copy prints of drawings displayed on the CRT screen. The magnetic tape unit provides mass storage for digitizer control programs and model/object drawings created at the digitizer terminal. The central processing facility consists of a minicomputer system controller and a 2.4 million word moving head disk unit. The system controller interprets and implements control programs read from the magnetic tape unit, executes system commands, and controls data flow between the tabletizer terminal and drawing storage. The disk unit provides intermediate storage of in-process drawings and the magnetic tape provides mass storage of completed drawings. Upon completion of a set of models and objects for a given data base, the magnetic tape is removed from the digitizer station tape unit and loaded into the data base generation facility computer tape unit for conversion to the data formats required for CIG visual data bases.

Data Base Generation Facility Computer. The data base generation facility computer consists of a VAX-11/780, 32-bit word general-purpose digital computer and associated peripherals manufactured by the Digital Equipment Corporation. The computer functional configuration is shown in figure 10 and includes the following equipment:

a. 11/780-CE Central Processor Unit with 128K byte Error Correcting Code (ECC) MOS memory

b. MS780-AB 128K byte ECC MOS memory

c. REM03-AA 67 megabyte [illegible] drive and control

d. Two TE16-Magnetic tape [illegible] control units (800 or 1600 bpi)

e. DZ11-A 8-line EIA interface

f. Two VT 52AA Data Entry Consoles

g. LA-36 DECwriter Termianl

h. LP11-DA Line Printer

i. CR11 Card Reader

The computer employs a VAX/VMS virtual memory operating system and incorporates an optional FORTRAN-IV PLUS program language compiler.

As shown in figure 11, computer hardware is mounted in five cabinets: a VAX11/780 processor cabinet, a UNIBUS expansion cabinet, two magnetic tape cabinets, and a disk cabinet.

The processor cabinet houses the CPU, two 128-byte MOS memory units and memory controller, a single unibus adapter, one massbus adapter, an intelligent microcomputer console with floppy disk memory, a time-of-day clock and power supplies.

The unibus extension cabinet houses a single DZ11-A, 8-line asynchronous multiplexor and distribution panel for EIA terminal interfaces.

The magnetic tape unit consoles contains the TE16-AE magnetic tape drives and control units and the disk cabinet houses the REM03-AA disk drive and control.

The Central Processing Unit (CPU) performs the logical and arithmetic operations defined by the system operating software. It includes sixteen 32-bit registers, 32 priority interrupt levels, an 8K byte cache memory, integral memory management and a programmable real-time clock. The CPU also provides 12K bytes of writeable diagnostic control storage for diagnostic programs loaded via the program console floppy disk memory. The CPU communicates with other processor components via a 64-bit high-speed Synchronous Backplane Interconnect (SBI) bus as shown in figure 12. A single memory controller connected to the SBI bus provides CPU control of two 128K-byte MOS memory units.

The processor console enables an operator to control processor operation directly. It consists of the console terminal, an LSI-11 microprocessor with 24K-byte memory and a floppy disk unit.

The CPU communicates with the REM03 disk unit and the TE16 magnetic tape units via the high-speed Massbus and the Massbus adapter housed in the processor cabinet. Communication with the data entry console is accomplished via the Unibus and the Unibus adapter in the Unibus expansion cabinet.

Camera Station. The data base generation facility camera station consists of a Color Image Recorder, Model D-47 manufactured by the DICOMED Corporation. The image recorder consists of a high-resolution CRT, operator control console, a 4 by 5 polaroid camera and a 35-mm movie camera. The image recorder is interfaced with the data base generation computer via a DR11-B computer interface terminal. The image recorder provides multiple resolution control whereby visual images may be displayed at low, medium or high resolution (1024 by 1024 pixels, 2048 by 2048 pixels, and 4096 by 4096 pixels, respectively).

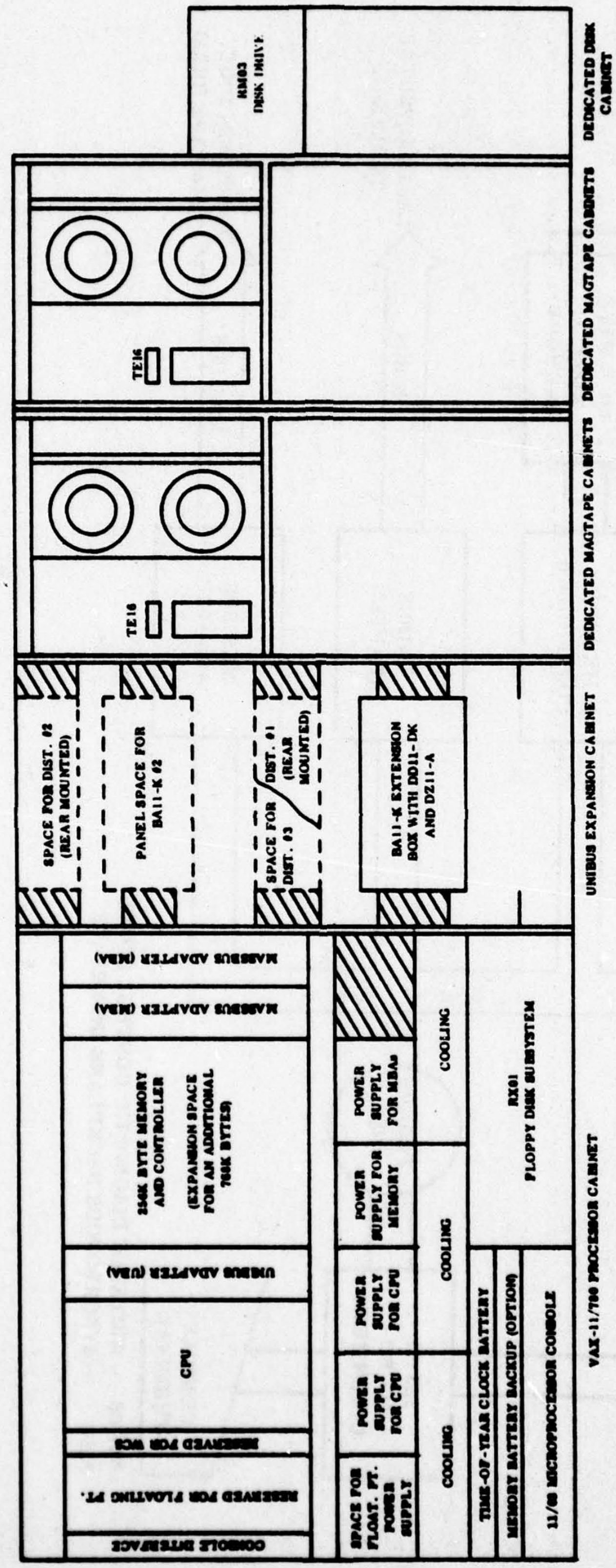


Figure 11. VAX 11-780 Cabinet Configuration

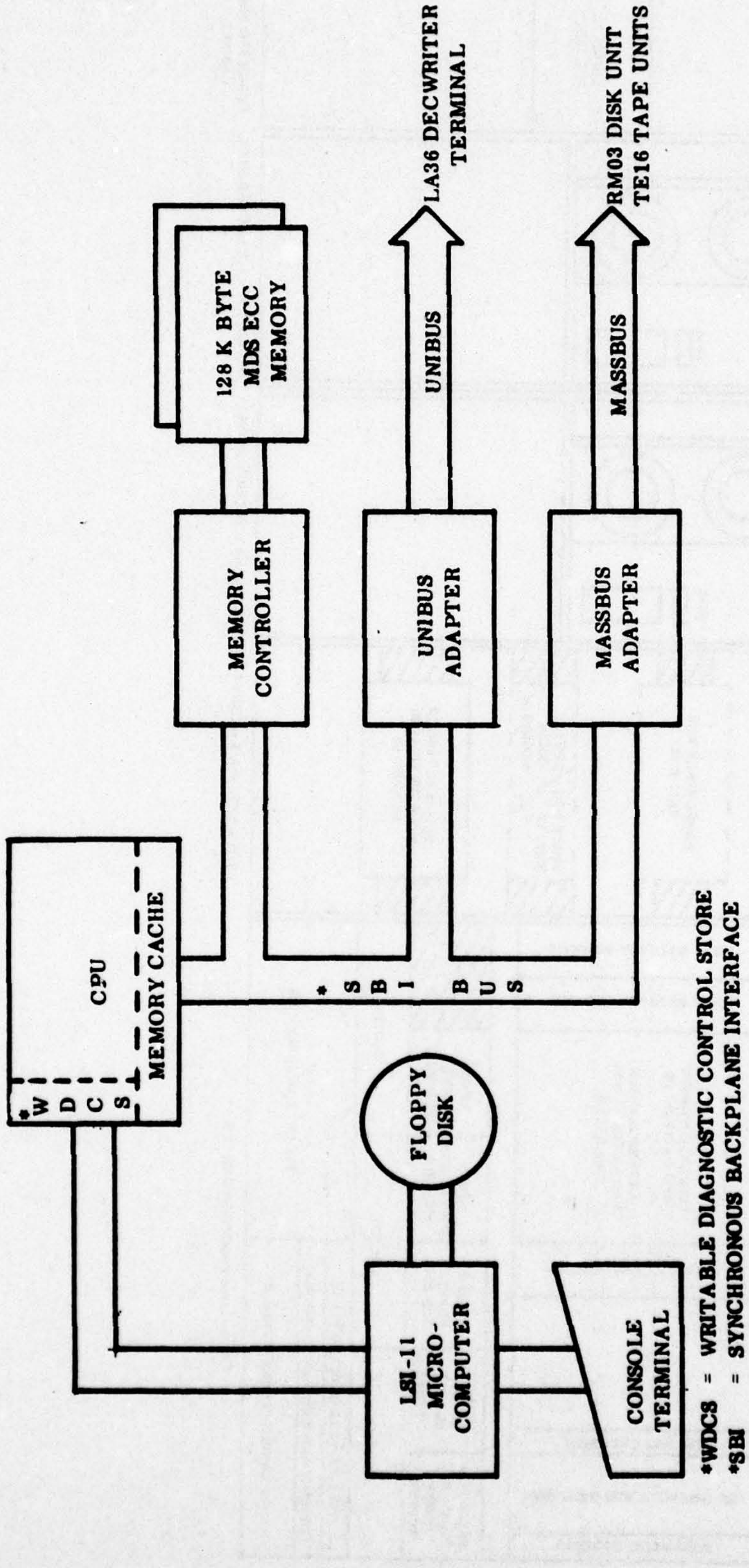


Figure 12. VAX 11-780 CPU Interfaces

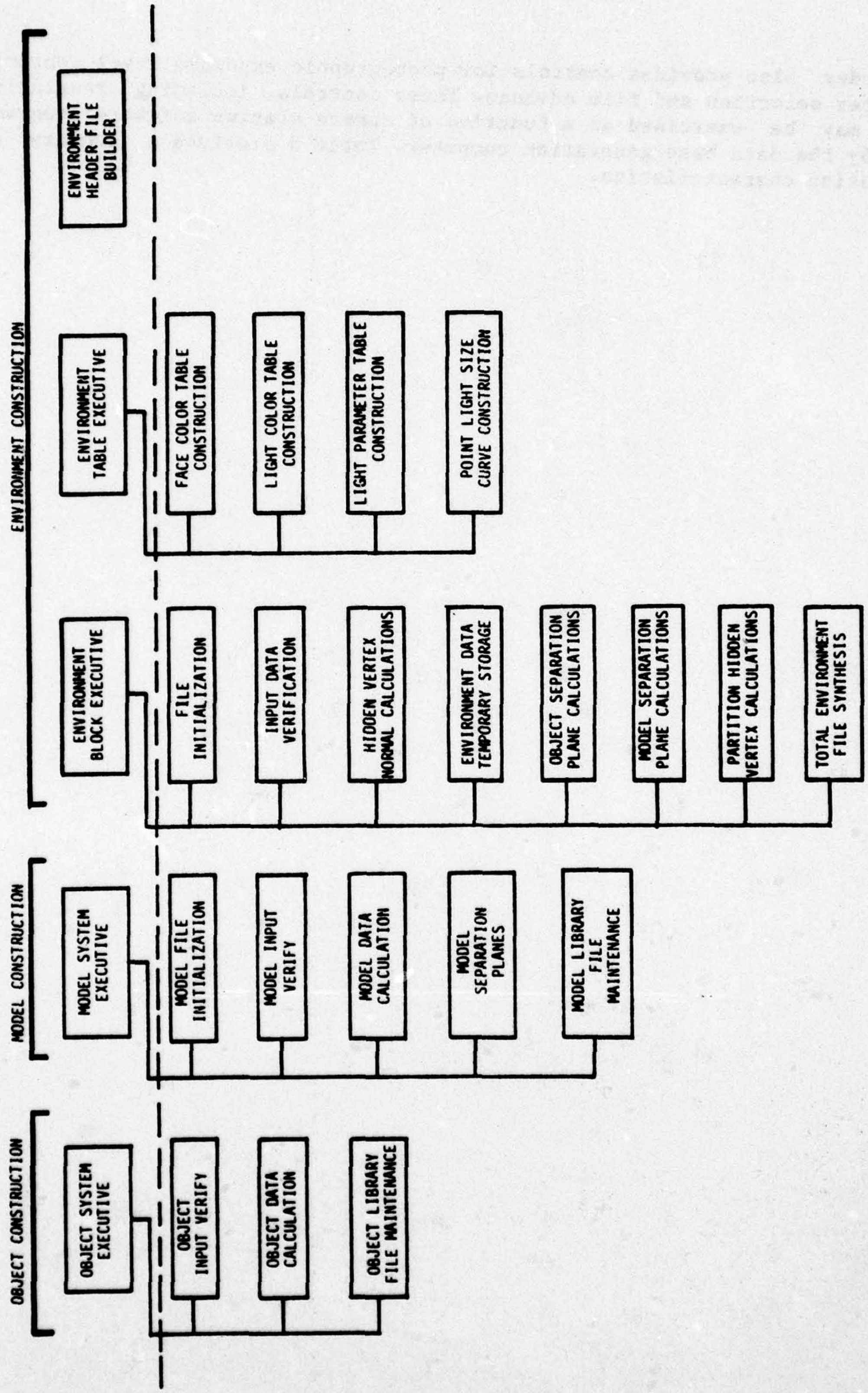


Figure 13. Data Base Generation Software Hierarchy

The recorder also provides controls for photographic exposure level control, color filter selection and film advance. These controls, including resolution control, may be exercised as a function of camera station software programs executed by the data base generation computer. Table 5 provides a summary of camera station characteristics.

TABLE 5. CAMERA STATION CHARACTERISTICS

Plotting Matrix--Low Resolution	1024 by 1024 Picture Elements
--Medium Resolution	2048 by 2048 Picture Elements
--High Resolution	4096 by 4096 Picture Elements
Variable Resolution	
--Full Format Exposure	Integral Fractions of Above
--Reduced Format Exposure	Any Non-Integral Values of Above
Film Format	100 Feet, 35mm Magazine Polaroid Film Holder Model 405
Exposure Levels	256
Exposure Range	Extrachrome 6115 - 2.0D Plus X Pan 4147 - 1.8D
Exposure Uniformity	$\pm$0.35D Maximum
Exposure Control	Yes
Recording Speed--Black/White	5.5 Min (Nominal Maximum Time for
--Color	16.5 Min High Resolution)
Interface Signals	Data Control Commands Recorder Status Codes
CIG Simulation	Raster Scan
Data Base	Common with Real-Time CIG
Scene Content Statistics	Yes
Predeermined Flight Path	Yes
Simulation of Real-Time CIG	Yes--Nonreal-Time

DATA BASE GENERATION SOFTWARE

The data base generation software consists of object digitizer routines executed by the data base digitizer station, a data format conversion program and five batch mode software systems for object, model and environment construction. The object digitizer software is a proprietary software package provided by the digitizer station manufacturer. The object, model and environment construction programs are stored on a magnetic disk which is loaded into the data base generation facility computer via the RM03 magnetic disk unit. The systems are selected and initiated via operator keyboard dialog with the computer operating system. When a system is thus selected, the appropriate executive routine is loaded into CPU memory and assumes control of subsequent processor activities. The hierarchial arrangement of the system programs is illustrated in figure 13. The executive control routines for each system provide subsequent operator dialog for operator interaction with the programs.

The object system consists of an executive control routine and three subroutines identified as object verification, object calculation and object file maintenance. Object data sets input via punched cards or via the converted digitizer station tape, are processed through each of these programs and checked for errors. Valid object data is stored in an object library file and an object directory file. Data errors are noted and a list of errors is printed at the operator's DECwriter terminal and on the line printer.

The model system consists of an executive control program and five principal subroutines identified as model file initialization, model verification, model calculation, model separation, and model file maintenance.

The model executive control program calls and sequentially pages model system subprograms into CPU memory, provides operator data entry console dialog and generates error messages to inform the operator of modeling errors.

The model system subroutines retrieves selected objects from the object library. These objects may be modified, if desired, and regrouped into larger constructions - models. The new models are then stored in the model library which is a completely separate data structure from the object library. Special model definition and control parameter including face normals, model centroids and directional components are also computed at this point.

The final environment construction is a three-phase process. First, the Environment Block program is used to extract selected models from the model library and combine them in a complete, independent coordinate system within the environment. Next, the Environment Table program is used to define the four major categories of environment control tables. These are the Face Color Table, the Light Color Table, the Light Parameter Table and the Point Light Size Curve Tables. Finally, all of these components are combined to form a complete environment description through the Environment Set program. This program does not physically reorganize the existing data structures, rather it builds a small header file that indirectly refrences all environment components. This hierarchial data base structure is diagrammed in figure 14.

Camera Station Software. The Camera Station software represents a software implementation of the real-time image generation processes performed by the Image Generation subsystem. Each of the major algorithms are simulated in one or more subroutines, allowing for a convenient means of altering an algorithm to determine its effects on other functions and on the final scene.

The bulk of the software is written in FORTRAN with assembly-language routines used for I/O interfacing to speed up processing time.

Data bases are of the same format as those processed by real-time Image Generation subsystem, but since the update rate is unrestricted, data bases may be much larger and more complex in detail.

Executive Control Segment. The Camera Station system operates from a core-resident executive. It calls major function subroutines in an order corresponding to the processing done by the real-time system; i.e., Frame I, Frame II, Frame III.

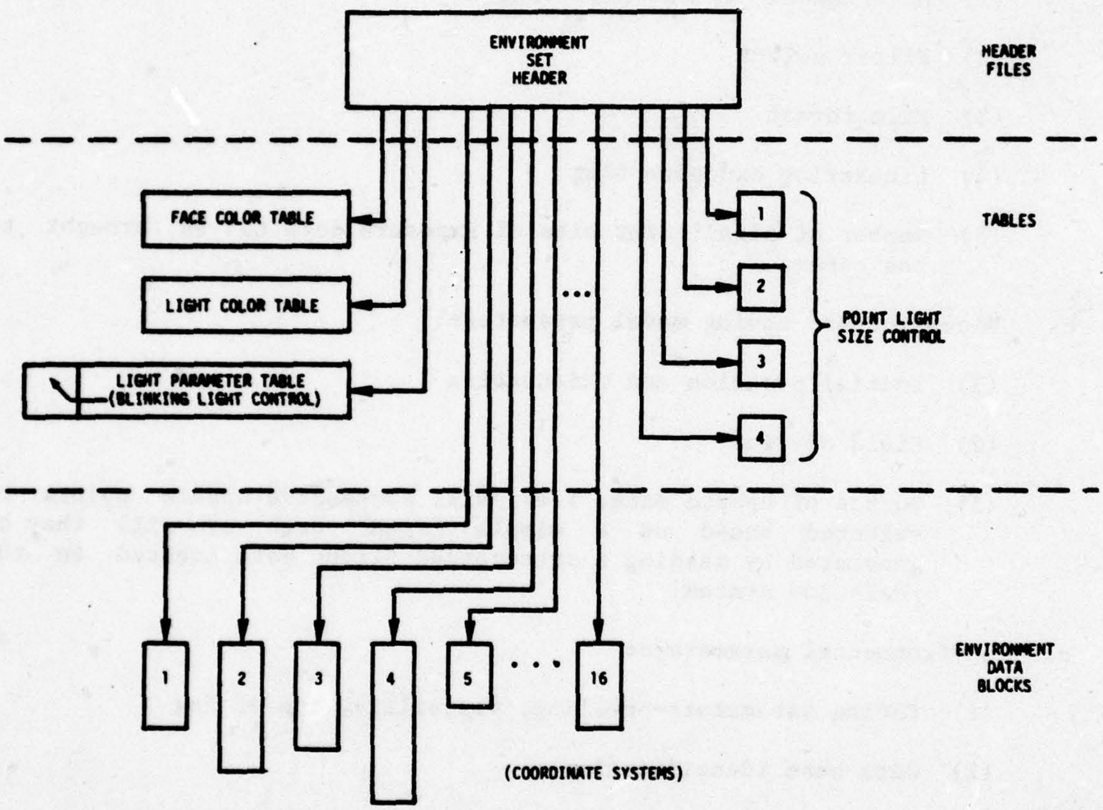


Figure 14. AWAVS Data Base Structure

Initialization Segment. The initialization segment is called once per run by the executive. It inputs the operating parameters for a run and sets up a control block in a common area of core, accessible to all subsequent segments. It is not needed again until the requested number of scenes has been produced on the camera.

Input data consists of:

a. Camera control parameters:

(1) Auto/manual film advance flag

(2) Filter select

(3) Film format

(4) Linear/log exposure flag

(5) Number of significant bits of exposure data to be brought to the camera.

b. Viewpoint and moving model parameters:

(1) Initial position and orientation

(2) Field of view

(3) Source of update data, i.e., will successive update points be selected based on a simple linear path or will they be generated by reading a prerecorded flight path created on the real-time system?

c. Environmental parameters:

(1) Fading parameters--ceiling, visibility, top of fog

(2) Data base identification

(3) Curved surface shading enable/disable flag

(4) Time of day

d. Computational parameters:

(1) Number of lines and elements to be computed

(2) Statistical output flag--to enable or disable the printing of various data during processing, such as the number of objects and edges in the scene, maximum number of edge crossings per raster line, etc.

(3) Number of scenes to generate for this set of parameters

Simulation Segments. There are four CIG simulation program segments: Frame I, Frame II, Priority Processor and Frame III. Each performs the same functions as its counterpart in the real-time system. Once initialization has taken place, the four segments are called in order by the executive for each scene to be generated, with Frame III providing the output to the camera. Disc storage is used as a buffer for storing edge control words generated by Frame II. Once Frame II processing is complete for a scene, Frame III will access the buffer for line-by-line output to the camera.

SECTION III

FUNCTIONAL DESCRIPTION

GENERAL

This section provides functional descriptions of operations performed by the Image Generation and Data Base Generation Facility subsystems.

IMAGE PROCESSOR FUNCTIONS

The following paragraphs provide a functional description of the processes and basic algorithms employed in generating real-time television raster displays of simulated flight environment scenes. The descriptions are presented in terms of the Frame I, Frame II and Frame III processing cycles described in Section I and define functional elements of the general-purpose computer and image processor involved in the processes.

ENVIRONMENT DATA

The environmental data base from which video scenes are generated is stored on magnetic disk and subsequently transferred to the general-purpose computer core memory for access by the image processor. The data base consists of numerical definitions of ground and cultural features within a 345 by 345 nautical mile square area. The data base also contains numerical definitions of moving models which can be moved about in the environment scene. The numerical definitions are presented in three-dimensional space vector notations with physical features and moving models oriented with respect to a three-dimensional reference coordinate system. As a result of these vector definitions of data base features, many of the computations performed in generating real-time images involve vector manipulations to translate environment features to television raster view window images.

Within the data base, two and three-dimensional features are defined by convex faces which are individually defined by circumscribing edges. Each edge is defined by a line segment with origin at one vertex and terminus at a second vertex. These vertices which ultimately define the extremities of features and objectives are oriented in the three-dimensional environment with respect to a three-dimensional environmental coordinate system or in the case of moving models, with respect to a three-dimensional moving model coordinate system. Since the location of the moving model coordinate system origin with respect to the environment coordinate system is known, any feature or model in the environment can be defined in terms of its location with respect to the environment coordinate system. Figure 15 illustrates the reference coordinate system and the other coordinate systems that may be used in the computation. For a given vertex, such as the one labeled X_1, Y_1, Z_1 in figure 15 the vector (V_1) would have a tail at the origin of reference coordinates (0, 0, 0) and a head at X_1, Y_1, Z_1. Each vertex in the environment is described in this manner with respect to either the reference or a moving coordinate systems.

Since the pilot's eye position moves throughout the environment, a moving coordinate system is assigned to the eyepoint. The motion of this coordinate

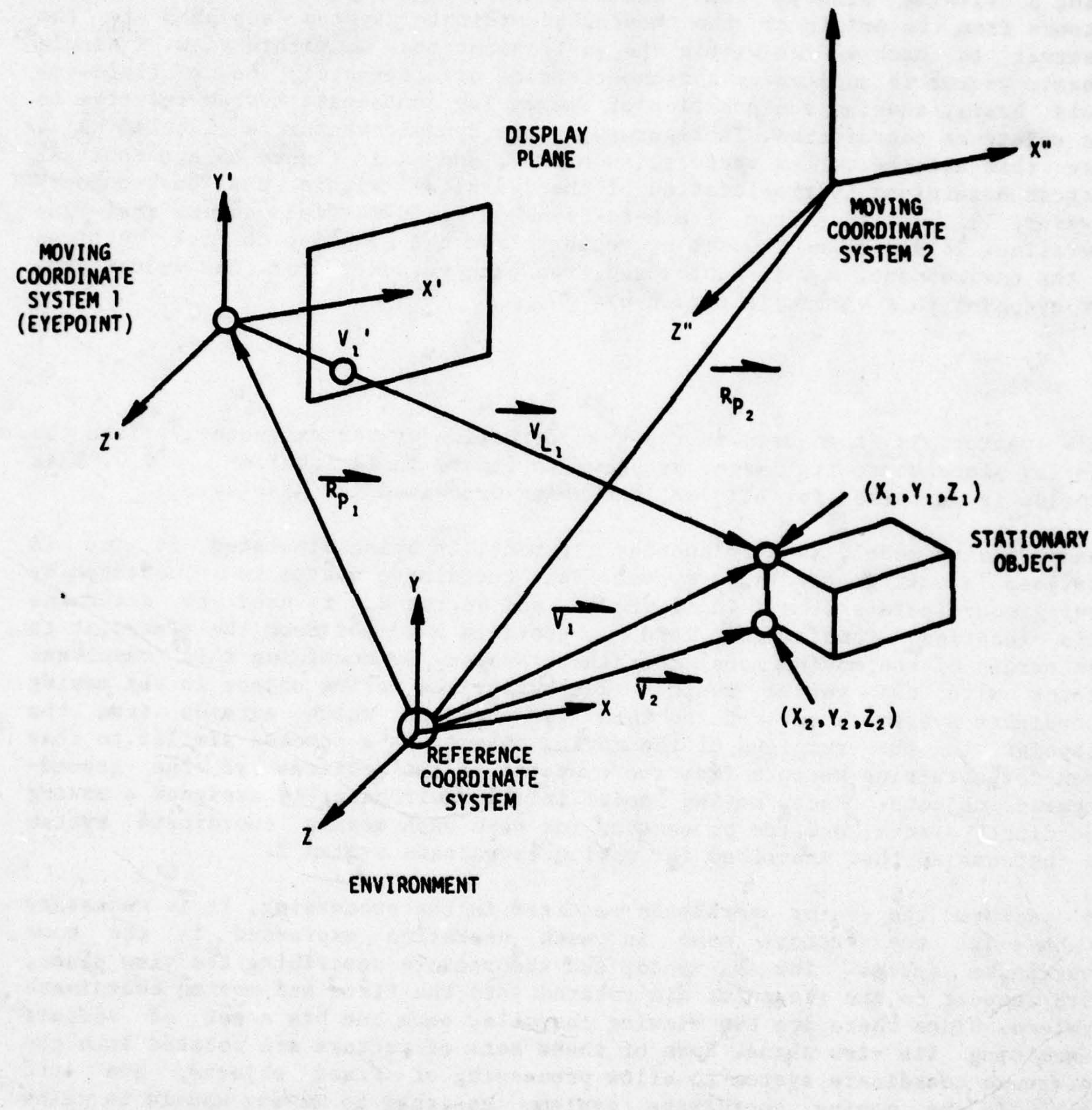


Figure 15. Image Generation Coordinate System

system in the environment corresponds to that described by the input data from the dynamics simulation in the AWAVS simulation computer that generates motion variables for moving models and viewpoints. To produce the scene for viewing, it is necessary to transform the vertices and edges that form the objects in the scene, into a two-dimensional display plane that corresponds to the pilot's viewing window. This transformation requires that a set of vectors extends from the origin of the moving coordinate system assigned to the observer to each vertex within the environment that is within view. A single dynamic vector is updated on a frame-to-frame or alternately on a field-to-field basis, showing the position of the moving coordinate system relative to the reference coordinates. In figure 15 this dynamic vector is labeled $\vec{R}_{P1}$. Note that all the vertex vectors, such as $\vec{V}_1$ and $\vec{V}_2$ in figure 15 are constant vectors determined by the location of the vertices within the environment. However, $\vec{R}_{P1}$ varies from frame-to-frame or field-to-field during real-time operation. To determine the set of vectors from the eyepoint to the vertices in the environment, $\vec{R}_{P1}$ is subtracted from each vertex vector. The vector from the eyepoint to a vertex is formed by:

$$\vec{V}_{L_1} = \vec{V}_1 - \vec{R}_{P_1}$$

This vector is then used in the transformation of vertex vector $\vec{V}_1$ into the display plane where its image, as shown in figure 15 is labeled $\vec{V}_1'$. This process is performed for all vertices being processed for display.

When a moving model, such as another aircraft, is being simulated, it too is assigned a moving coordinate system. This coordinate system is illustrated by moving coordinate system 2 in figure 15, and vector $\vec{R}_{P2}$ is used to determine this location. Combining $\vec{R}_{P1}$ and $\vec{R}_{P2}$ provides a vector from the viewpoint to the origin of the moving model coordinate system. By combining this resultant vector with the vertex vectors describing the moving object in the moving coordinate system, a set of vectors is obtained which extends from the eyepoint to the vertices of the moving object, in a process similar to that used for obtaining vectors from the eyepoint to the vertices of the ground-located objects. Each moving model in the environment is assigned a moving coordinate system, and the processing for each such moving coordinate system is the same as that described for moving coordinate system 2.

To perform the vector operations required in the processing, it is necessary to have all the vectors used in each operation expressed in the same coordinate system. The $\vec{R}_P$ vector and the vectors describing the view plane, with respect to the viewpoint are rotated into the fixed and moving coordinate systems. Since there are two viewing channels, each one has a set of vectors describing its view plane. Each of these sets of vectors are rotated into the reference coordinate system to allow processing of fixed objects, and into each of the moving coordinate systems assigned to moving models to allow processing of moving models. This provides a consistent set of vectors for each coordinate system, so that all the operations can be performed. The resulting vector operations provide scene data that can be displayed for view from the single eyepoint with accurate perspective.

The intersection of each eye-to-vertex vector with the display plane gives the perspective transformation of the vertex data to the viewing surface, and the lines connecting the associated vertex images are the transformed image of the respective edges in the environment model. The display-plane coordinates of

the vertex images (e.g., V_1',) expressed in the raster line number and raster element number, and the slopes of the edges connecting them, in number of elements per line, are used to generate the raster-line video.

PROCESSING CYCLES

To accomplish the vector processing and to compute the visual scene, three major data processing cycles run concurrently in the Image Generation subsystem; one in the general-purpose computer and two in the image processor. These computation cycles are slaved to the selected update rate and are repeated each 1/60 second corresponding to the update rate. The three cycles are connected serially and, therefore, are referred to as Frame I, Frame II, and Frame III operations. These relationships are shown in figure 2. (The term "Frame" is used here for equipment and computation groupings and should not be confused with update rates.)

Frame I operations are performed by the general-purpose computer. During Frame I, the general-purpose computer utilizes data received from the AWAVS simulation computer. The data received by the general-purpose computer over the computer-to-computer interface consists of aircraft position and attitude; moving models position and attitude; environment control (i.e., cloud parameters, fog, night lighting selection, etc.); and discrete control functions as applicable.

The general-purpose computer then processes these inputs to generate data for the Frame II and III operations and any output messages to the operator's console that are consequential to the input data. The attitude and position data is used to calculate the observer's viewpoint position and orientation within the three-dimensional operating area. The instantaneous relative position and orientation of any pertinent moving models is calculated from the AWAVS-generated data inputs. Information calculated by the Frame I general-purpose computer is transmitted to the Frame II equipment modules via the Frame I/Frame II interface.

Two special data buses provide the communication links to all functions within Frame II and Frame III for both the general-purpose computer and a display and data entry (DDE) panel. These buses are used for on-line data transfers during real-time scene generation and for off-line test and diagnostic data transfers.

The general-purpose computer side of the interface with the special data buses consists of two direct memory access devices. Each of these is linked to a computer interface on a data bus. The DDE panel has access to both data buses to permit manual operator interaction with the data buses. All real-time operations with the AWAVS-CIG System are synchronized by the timing signals generated by master timing.

The Frame II and Frame III functions perform the real-time scene computations from the data base stored in Frame II memory. Frames II and III receive the viewpoint and moving model position and orientation data, fading (visibility) constants, and blinking light on/off states at the start of each update cycle from Frame I via the data bus. During the update cycle, Frame II computes a true perspective, two-dimensional image of the modeled environment for each of the two display channels. At the start of each cycle, Frame II transfers the computed two-dimensional images to Frame III in the form of up to 2048 edges, up to 2048 point lights, and a face priority list.

Each raster line time, Frame III computes analog video for each display channel from its two-dimensional image. Frame III provides the video for a two-to-one interlace, raster scan in synchronism with the sync signals furnished by the master timing equipment. In the AWAVS application, since only monochrome operation is initially required, the data bases will be constructed so as to generate video in shades of gray.

Frame I Operations. Frame I computations are performed by software programs executed by the general-purpose computer. The inputs to the Frame I computations are the dynamic position and orientation of the viewpoint and moving models from the AWAVS simulation computer and the display channel position and orientation constants.

Definition of Display Channel Constants. Each display channel view window has an individual coordinate set for definition of image vertices within the view window boundaries. The coordinate set is illustrated in figure 16. The U vector is perpendicular to the window plane, the V vector is positive in the direction of increasing element number (J) and the W vector is positive in the direction of increasing line number (I). The orientation of each window with respect to the viewpoint is defined by roll, pitch and yaw in viewpoint coordinates. For subsequent definition of view window boundaries in viewpoint coordinates; each unit vector of the window coordinate system is rotated into viewpoint coordinates by means of a direction cosine matrix. For view windows with fixed orientation with respect to the viewpoint, the view window definition in viewpoint coordinates can be computed off-line and stored in Frame I. For nonstatic view windows such as the target projector window the window orientation with respect to the viewpoint changes and must be dynamically updated.

Thus the rotation of target projector window coordinates into viewpoint coordinates is recomputed each frame time on the basis of camera probe motion dynamics data received from the AWAVS simulation computer.

Additional scaling constants are computed to relate view window definitions to line and elements for each of the program selectable raster line resolution rates (525, 825 or 1023 lines). The constants are stored and subsequently selected for application based on the selected line resolution rate.

Functional Computations Performed. Figure 17 is a sequential flow diagram of the functional computations performed during the execution of the Visual Image Processing Task. It is constructed in an unscaled time-phase fashion to show the logical execution of major functions and their time relationship to subsequent functions. Each major function is described in the following subparagraphs.

a. Bookkeeping Activites: In order to synchronize the arrival of Frame I, control data at the Frame II and Frame III processing stages some data is initially computed and stored in delay buffers in the general-purpose computer. At the beginning of each cycle, these buffers are copied into the appropriate output buffers for transmission to the Image Generator hardware. Other routine bookkeeping activities are also performed at this stage.

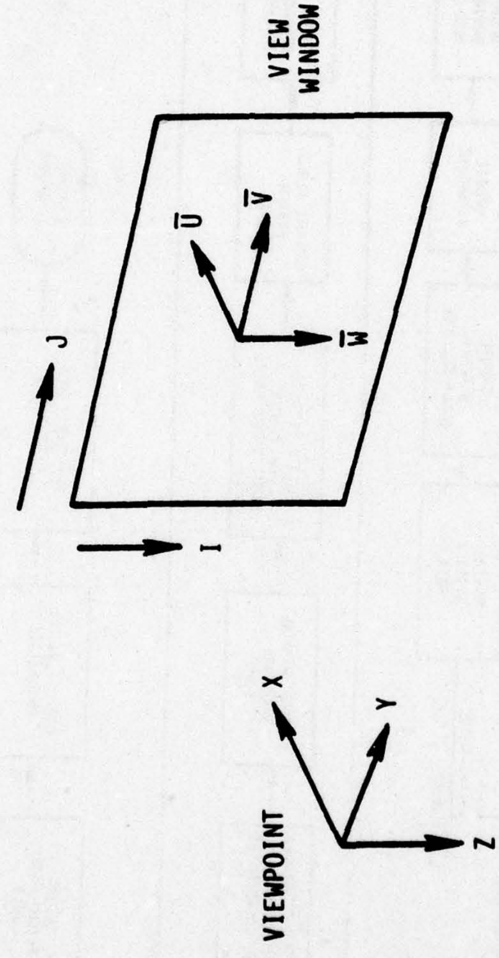


Figure 16. Viewpoint and View Window Coordinate Systems

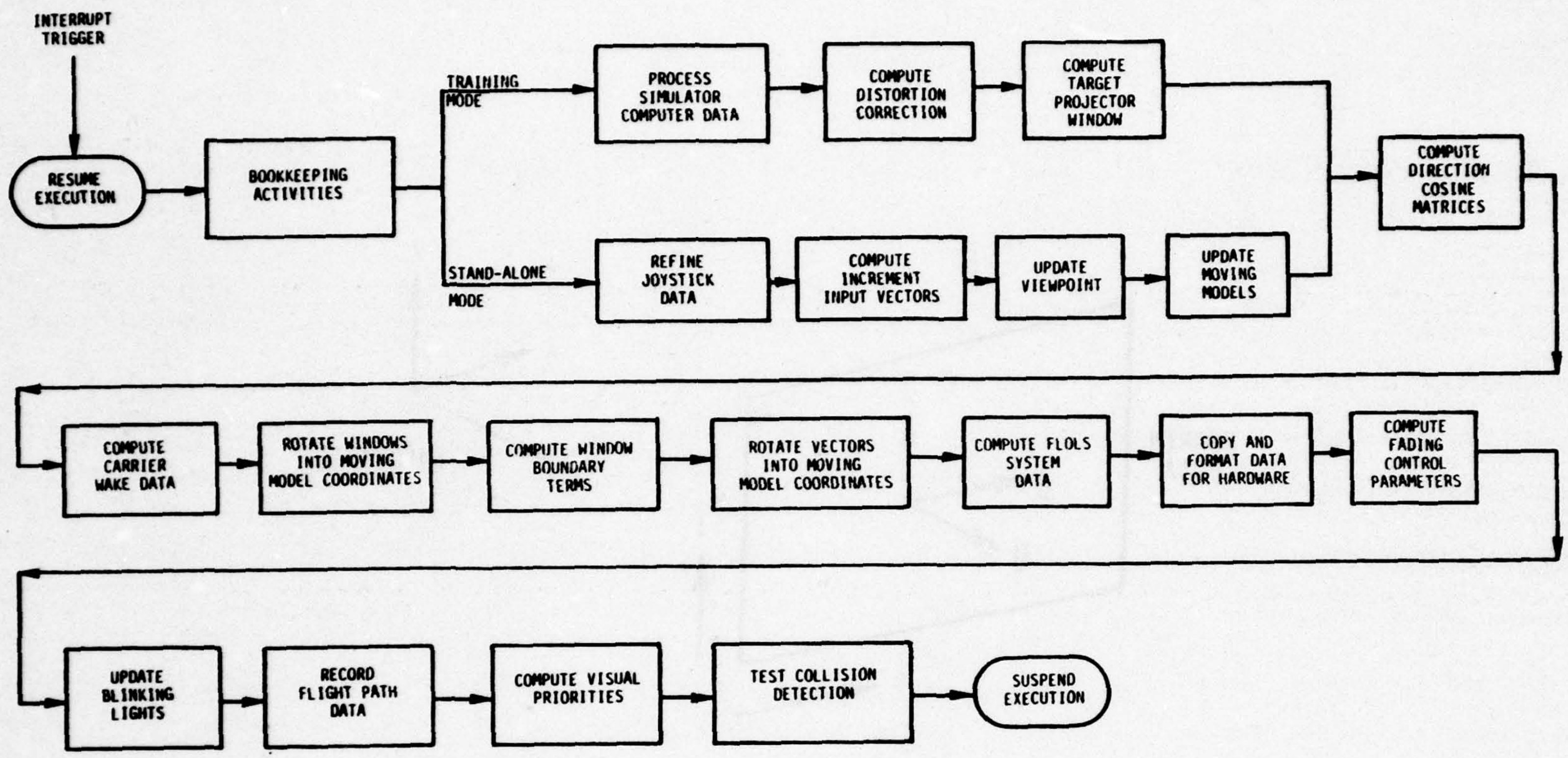


Figure 17. Frame I Computational Sequence

TRAINING MODE

b. Process Simulator Computer Data: This module either copies or extrapolates viewpoint and moving model dynamics data received from the Host simulator into CIG data structures. It also controls the integration of discrete data commands (visibility, fog layer, and data base selection) into the ART control stream.

c. Compute Distortion Correction: This subroutine computes the dynamic predistortion necessary to minimize the effects of horizontal keystone distortion in the display system.

d. Compute Target Projector Window: This subroutine redefines the size and orientation of the target image display window based on the camera probe orientation and the target projector zoom lens setting.

STAND-ALONE MODE

e. Refine Joystick Data: This routine scales the inputs from the joystick A/D channels in order to simulate the behavior of functionally identical resistors. It also maps the linear input data into a cubic function for the special performance required by the DEBUG dynamics algorithm.

f. Compute Increment Input Vectors: This module converts the input translation and rotation, vectors from relative (viewpoint or moving model) coordinates to absolute (earth axis) coordinates. For example, translational information defined in terms of fore-aft, left-right, and up-down distances is converted into X, Y, and Z in earth coordinates.

g. Update Viewpoint: This subroutine updates the position and attitude of viewpoint #1 or #2 based on either the FLIGHT or DEBUG dynamics algorithm.

h. Update Moving Models: This subroutine updates the position and attitude of the major moving models (#1, #2, #3) based on the FLIGHT algorithm, the DEBUG algorithm, or a preprogrammed path.

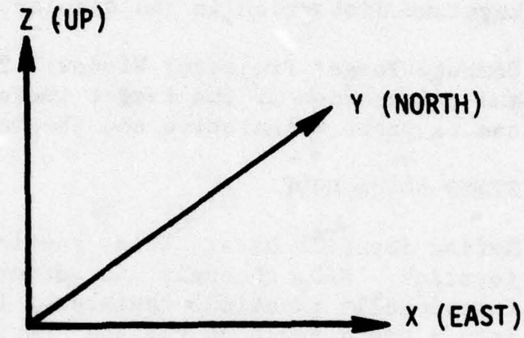
IMAGE PROCESSING CALCULATIONS

i. Compute Direction Cosine Matrices: Direction cosine matrices are used to rotate vectors in one coordinate system into another coordinate system. These matrices are formed by the selective association of the sines and cosines of the three orientation angles - roll, pitch, and yaw (heading). This routine computes the direction cosine matrices for the current viewpoint and the major moving models.

AWAVS coordinate systems are standard right-handed coordinate sets defined as shown in figure 18. The rotation angles for the moving model and viewpoint simulation shall be:

Positive Pitch - (Z into X) Nose Up
Positive Yaw - (X into Y) Turn Right
Positive Roll - (Y into Z) Right Wing Down

THE EARTH AXIS COORDINATE SYSTEM IS DEFINED AS FOLLOWS:



THE MOVING MODELS COORDINATE SYSTEMS ARE DEFINED AS FOLLOWS:

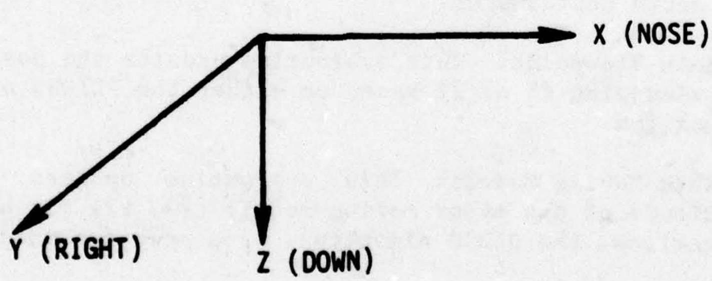


Figure 18. Earth and Moving Model Reference Coordinate

j. Compute Carrier Wake Data: The carrier wake is defined to have the same position and heading as the carrier, itself. Roll and pitch components of the carrier attitude are eliminated.

k. Rotate Windows Into Moving Model Coordinates: After establishing the orientation of each window relative to the viewpoint origin, the window orientations are rotated into each moving model coordinate system for use in Frame II. The required rotations are obtained using the direction cosines computed and stored in a previous calculation.

l. Compute Window Boundary Terms: To simplify calculations necessary to ultimately locate vertices in terms of television raster lines and elements, each window coordinate set origin is translated from window center to the upper left corner of the window frame. This is accomplished using the window descriptions in each moving model coordinate system.

m. Rotate Vectors Into Moving Model Coordinates: The computations that project each moving model onto the view screens is computed in the coordinate system of that moving model. Therefore the vector from the origin of the moving model to the viewpoint must be rotated into that moving model system. These rotations are accomplished in this module using the proper combination of direction cosine matrices previously computed.

n. Compute FLOLS System Data: The Fresnel Lens Optical Landing System (FLOLS) is composed of two independent moving models. These models must be positioned appropriately and the intensities of certain faces must be dynamically controlled in order to provide the proper approach glide slope information. A special calculation in this subroutine artificially enhances the display resolution of the entire FLOLS system in order to minimize the unrealistic image deterioration due to raster scan quantization effects at large distances.

o. Copy and Format Data for Hardware: This module performs some special data replication and formatting activities required for output to the Image Generation hardware.

p. Compute Fading Control Parameters: This module computes special control data for object fading in Frame II and surface fading (horizon fading) in Frame III. The positions of the viewpoint and all moving models with respect to the thickness and density of the fog layer are accounted for.

q. Update Blinking Lights: This subroutine turns all blinking lights on and off based on a Blinking Light Control Table stored with the environmental data base.

r. Record/Playback Flight Path Data: When requested by the operator, this module continually buffers five frames of position and attitude data and then writes it out to the magnetic tape for long-term

storage. This tape can then be used on the Camera Station System to provide a film of the prerecorded flight path or it can be replayed in real-time by the ART system.

s. Compute Visual Priorities: This program module performs a top-level scan of moving model visibility relationships. This scan produces a priority ordered list of model coordinate systems that is subsequently transferred to the Priority Processor for use in determining object priority.

t. Test Collision Detection: When the collision detection feature has been selected by the operator, this code examines the collision detection flag that is controlled by the Image Generation hardware. When a collision is detected, this routine requests the Operator Interface Task to report the condition and then suspends further collision monitoring for ten seconds.

Frame II Operations. The basic function of the Frame II processing is to compute a new two-dimensional image for each display channel during every raster field period. The display channel images are true-perspective scenes of the modeled environment as viewed from the current position and orientation of the viewpoint and display channel view planes. The viewpoint and moving model(s) position and orientation data are received from Frame I at the start of each raster field. The two-dimensional image data for the two display channels is transferred to Frame III at the start of each raster field as a block of up to 1024 edge data words and as a block of up to 2048 point light data words. A face priority list is also transferred to Frame III at the start of each *raster period*. The face priority list contains the relative priority relationships of the faces bounded by the edges in the edge data word block.

Figure 19 is a functional diagram of the Frame II Function. The Frame II functions, as shown, consist of environment store, vertex processor, sun angle processor, color processor, face edge processor, shading processor, point light orderer, priority data store, and priority processor. The computer terminal end of the image processor data buses is also shown. Although the data buses operate throughout the image processor, the computer terminal is shown in the Frame II diagram to illustrate its relationship to Frame II functions. All data transfers between the general-purpose computer and the image processor are performed via the data busses.

Environment Storage. The environment storage is capable of storing a single 10,000-edge, 2048-light data base or it may be segmented into a maximum of 16 data block sections each of which is treated as an independent data base. These data blocks are loaded, controlled and activated for processing under Frame I control. During alternate field periods the data base may be updated to add new active data blocks and to delete inactive data blocks.

The data base core memory consists of three separate core memories. These are referred to as the vertex pointer memory, vertex memory, and vertex normal memory. The vertex pointer memory contains the control words and address pointers that control access to the vertex memory and vertex normal memory by the vertex processor. Model centroid, face centroid, and vertex coordinate data are stored in the vertex memory while the vertex normal memory contains face normals and vertex normals. These three memories operate in parallel with a storage capacity of 24K, 32-bit words in the vertex pointer memory; 16K,

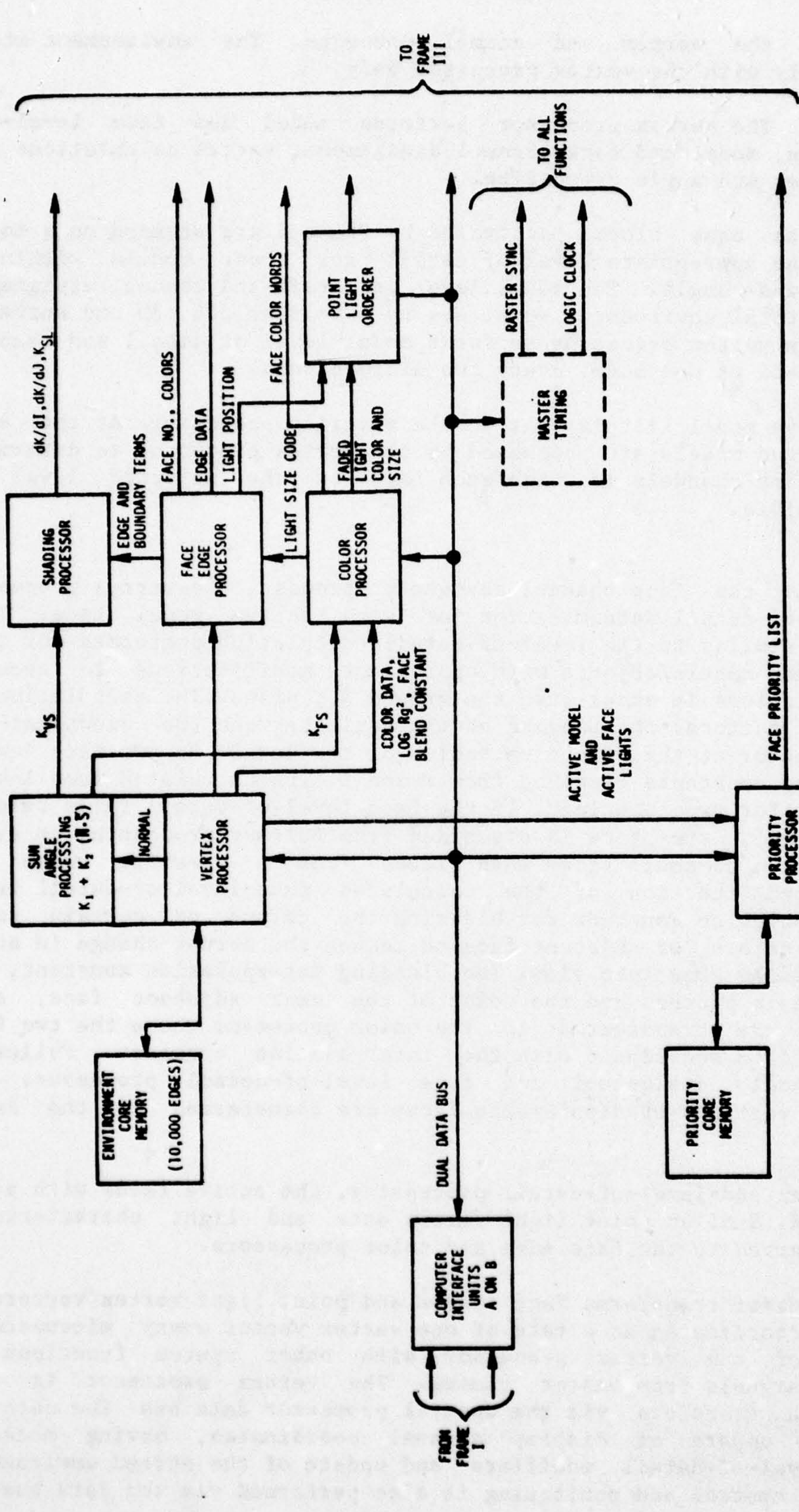


Figure 19. Frame II Functional Block Diagram

72-bit words in the vertex and normal memories. The environment store interfaces directly with the vertex processor only.

Vertex Processor. The vertex processor performs model and face level-of-detail computation, model and face channel assignment, vertex calculations and all face and vertex sun angle processing.

Environmental data base blocks activated by Frame I are scanned on a model basis to select the appropriate level of detail for those models within a viewable range and angle. The model level of detail and channel assignment selects from the total environment model set no more than 256 (3D and surface) active models. The vertex processor performs model level of detail and channel assignment at a rate of one model every two microseconds.

The selected active model list is sent to the priority processor. At the same time, the selected models are processed by the vertex processor to determine the specific display channels in which each face of the selected level of detail can be visible.

In parallel with the face channel assignment process, the vertex processor performs a level-of-detail determination for each active model face. This calculation is similar to the level-of-detail calculation performed for two-dimensional surface models/objects with appropriate modifications to account for face orientations in other than the ground X,Y plane. The calculation is based on these factors: the tangent of the angle between the viewpoint to model centroid vector at the effective radius of the model and two face level-of-detail/blending constants received from Frame I. The calculated face level-of-detail is used for two functions. If the face level-of-detail falls below a predetermined level, the face is discarded from further processing to avoid the apparent breakup of small faces when viewed from a specific range and angle. The second function of the calculated face level-of-detail is to provide an interpolation constant for blending the colors of certain small face with the colors of adjacent face to reduce the abrupt change in scene detail as small faces come into view. The blending interpolation constant, the color of the face in process and the color of the next adjacent face, sky, ground or haze are transferred to the color processor where the two face colors are blended in accordance with the interpolation constant. Following the face channel assignment and face level-of-detail processes, the transformed face vertices of displayable faces are transferred to the face-edge processor.

After face vertex and level-of-detail processing, the active faces with point lights are cycled. Similar point light vertex data and light characteristic codes are transferred to the face edge and color processors.

The vertex processor transforms face vertex and point light vertex vectors to display channel coordinates at a rate of one vertex vector every microsecond. The operation of the vertex processor with other system functions is synchronized by signals from master timing. The vertex processor is also capable of data transfers via the special processor data bus. The data bus provides on-line update of display channel coordinates, moving model(s) coordinates, level-of-detail modifiers and update of the stored environment data base. Test control and monitoring is also performed via the data bus.

Sun Angle Processing. The vertex processor computes a single color intensity modifier for each sun illuminated face and a color intensity modifier for each vertex of a curved face.

The computation to obtain a sun illumination effect is of the general form

$$K_s = K_1 + K_2 \cos\theta$$

where

$$(K_1 + K_2) \leq 1$$

The K_1 term accounts for diffuse illumination while the K_2 term accounts for direct illumination. The stored data base contains a normal to the face (N_F) for each face. In addition, for curved faces the data base contains a vector (N_V) representing a normal to the curved surface at each vertex. The color intensity modifiers are computed for faces (K_{FS}) and vertices (K_{VS}) as follows:

$$K_{FS} = K_1 + K_2 (\vec{N}_F \quad \vec{S})$$
$$K_{VS} = K_1 + K_2 (\vec{N}_V \quad \vec{S})$$

where

$$(\vec{N} \quad \vec{S}) = \cos\theta \text{ (angle of incidence)}$$

The constants (K_1 and K_2) controlling the proportions of diffuse and direct illumination, and the sun direction vector(s) may be varied on-line to simulate changing conditions or they may remain fixed. These may be updated by the Frame I software via the data bus. A separate set of constants is utilized for each independent coordinate set, since the normals will be defined in terms of the appropriate coordinate system, i.e., fixed environment, ship, airplane, etc.

The face normals (N_F) processed during the face channel assignment cycle, while the vertex normals (N_V) are processed during the face-edge cycle. The vertex color intensity modifier is transferred to the shading processor and the face intensity modifier is transferred to the color processor.

Color Processor. The color processor provides color data for each active face and light. The current design configuration provides 256 separate colors (gray shades) for face coloring and 256 separate colors for point light coloring; however the color processor has been designed such that it can be expanded for full-color presentation by inserting additional color memory circuit boards.

In addition to assigning face and light colors, the color processor performs a series of color modifications to account for the effects of sun illumination, face color blending, light intensity and size variations with respect to range and color fading with respect to range. For each face or light processed, the color processor receives range data, color codes, face illumination constants, face blending constants and control words from the vertex processor that permit computation of the following color modification coefficients during face and vertex processing cycles.

Face Processing Cycle

Feature	Computation
Nonsurface Model Faces	Blending, sun illumination and fading
Surface Model Faces	Blending and sun illumination
Light Faces	Brightness and fading

Vertex Processing Cycle

Feature	Computation
Point Light	Brightness, size and fading
Light Faces	Minimum Size flag

Face blending is the first modification performed and involves blending face color with adjacent face or background color as a function of the face level of detail. Each set of face data received contains the face color code, the color code of the next adjacent face and a face level of detail modifier. The resulting blended face color is computed by the following algorithm:

$$\text{Blended Color } (C_{LD}) = C_{F2} + K_{FLD}\ (C_{F1} - C_{F2})$$

where

C_{F2} = selected next face, sky, haze or ground color

C_{F1} = color of face in process

K_{FLD} = face level of detail modifier

Face blending is applied to object/model faces only and does not affect lights or light faces.

The second color modification performed is a modification of model/object face color with respect to sun illumination intensity modifier (K_{FS}) calculated in the vertex processor as a function of sun angle, incident illumination and diffuse illumination. The intensity modifier is used to modify face color in accordance with the following algorithm:

$$\text{Modified Face Color } (C_{FMS}) = (K_{FS})\ (C_{LD})$$

where

K_{FS} = sun illumination intensity modifier in the range of $0 \leq K_{FS} \leq 1$.

C_{LD} = face blended color

The third color modification involves modifying light intensity as a function of light range from the viewpoint. A brightness coefficient is computed from range data received from the vertex processor and brightness constants read from a light parameter storage for the point light being processed. The resulting coefficient is constrained within the maximum brightness and extinguishing range brightness levels stored for the light being processed.

Point light size is likewise modified as a function of range from the viewpoint. The range data received from the vertex processor is used to access a light size curve lookup table which prescribes light size per range value. The computed light size is constrained within the limits prescribed by the maximum and minimum size values stored for the light being processed.

The final color modification process involves fading previusly modified nonsurface model face colors and point light colors toward a predetermined haze color as a function face or point light range from the viewpoint. Fading data is derived from a fading memory that stores separate sets of haze colors and fading factors for each coordinate set. These colors and fading factors are stored in range order and are accessed as a function of face or point light range data received from the vertex processor. The selected haze color is blended with the modified face or point light color in accordance with the fading factor to produce faded colors.

Following the fading process, the resulting modified face colors are stored for subsequent processing by the edge orderer. The modified point light color is transferred to the point light orderer and the point light size code is transferred to the face edge processor.

Face Edge Processor. The face edge processor transforms face vertices, in channel-specific viewpoint form, to potentially visible edges in the channel-specific viewplane. The edges bounding a face are processed sequentially in connective order. The view plane line and element numbers for the two vertex projections bounding each edge are determined. If an edge image, bounded in the viewplane by its vertex projections, intersects any view window boundary, the edge is truncated to the boundary intersection point. Pseudo edges are created along the left side of the view window for faces crossing the left boundary of a channel. Edge images outside the view window are discarded. All visible edges processed for a raster field are accumulated, and transferred to the edge generator and edge orderer of Frame III at the start of each raster period.

The face edge processor also computes the line and element numbers for point source centroid images in the view plane, and transfers this data to the point light orderer.

The face edge processor also interfaces with the shading processor and provides vertex-edge parameters and edge boundary crossing terms necessary for curved surface shading calculations.

The edge data words transferred to Frame III contain the face number to the left of the edge, the face number to the right of the edge, edge slope magnitude, slope sign, the edge vertices by line and element, edge shading data and the display channel number.

Shading Processor. The shading processor computes a color intensity modifier (K) for the left (K_L) and right (K_R) vertex image as each curved face edge image is processed by the face edge processor. Also, the shading processor computes the intensity modifier change per line along each edge (dK/dI) and the intensity modifier change per element (dK/dJ) for each face.

As the edges bounding each face are processed by the face edge processor, the shading processor computes the shading terms. For a noncurved surface face, (dK/dJ) equals zero, dK/dI equals zero, and the K_L and K_R of each edge bounding the face is set equal to one. The shading processor receives a color intensity modifier (K_{Vi}) for each vertex of a curved surface face. These are received from the sun angle processor sequentially as each vertex is processed by the vertex processor. The first two edges and associated vertices are used to calculate the dK/dJ for the face. As each edge is processed, the K_L, K_R, and dK/dI terms will be determined for each edge.

At the end of each face cycle, the shading processor calculates boundary crossing (K_{LC}) values for the end points of any pseudo-edges.

The shading data for all active edges processed during a raster field period are accumulated and transferred to the shading generator at the start of the next field period.

Point Light Orderer. The point light orderer receives and stores point light words from the face edge processor and color processor, arranges the point light data in order of the point light element position and outputs the ordered set of point light data to the point light generator.

The point light orderer receives and stores up to 2048 point light data words during each raster field period. Each word contains the point light color, assigned channel number, size code and raster line and element location of the top left corner of the light. The orderer scans the stored point light data element numbers, counts the number of point lights with the same element position, creates a memory accession address lists in ascending element number order and provides a point light generator memory address for each point light data word. This process effectively arranges the point light data in ascending element number order. At the end of the raster field, the point light order transfers the ordered point light data words and corresponding point light generator memory addresses to the point light generator.

Priority Data Store. The priority data store consists of an 8K-word, 32-bits per word, core memory. This memory contains the environment model and object separation plane data and associated separation-plane data for each corresponding data base in the environment store. This data is used by the priority processor in establishing the relative priority of models and objects in the visual scene. The memory can be updated with a new data base from the general-purpose computer via the data bus during on-line operation.

Priority Processor. As a function of the viewpoint location in the environment and an active nonsurface model list from the vertex processor, the priority processor constructs a priority list containing a unique priority number for each object of the active nonsurface model set. The priority relationships are determined by means of separation plane data for nonsurface environment data base items stored in the priority data store.

The priority processor is capable of creating an active priority list with up to 128 unique priority numbers. The larger priority number is assigned to the entry with the higher priority. The lowest 16 priority numbers (0-15) are reserved for surface objects and the higher priority numbers (16-127) are assigned to nonsurface objects.

An active face list from the vertex processor is combined with the object priority list to obtain a face priority list for the priority resolver.

Frame III Operations. The Frame III functions convert the two-dimensional image data received from Frame II into noncomposite video synchronized to the display device raster scan. The two-dimensional image data is scanned in a standard raster format having two-to-one interlace. The odd-field lines are computed in the first field period of the frame and the even-field lines in the second field period.

The two-dimensional image data is received from Frame II at the start of each field period (except for two-viewpoint operation). This data consists of up to 1024 edge data words and up to 2048 point light data words. Expansion capability incorporated in the hardware design permits future expansion to 2048 edge data words and 4096 point light data words by inserting additional circuit boards in available board slots. Frame III also receives a face priority list that defines the priority relationships of the faces bounded by edges contained in the edge data word block and surface fading terms from Frame I at the start of each raster period. A separate set of fading data is provided for each video channel.

Figure 20 is a functional block diagram of Frame III showing the significant functions to be a point light generator, edge/shading generator, edge orderer, priority resolver and a video processor for each display channel. The image processor data bus interfaces with all Frame III functions. The Frame III functions also receive frame, field, line, and element syncs as required from the master timing function.

Point Light Generator. The point light generator is currently capable of receiving and processing up to 2048 point lights each field of a raster frame and can be expanded to 4096 point lights. During each active line time of a field, the point light generator outputs only the visible point lights for the active line. For a raster having 525 lines, the point light generator is capable of processing and outputting data for up to 500 point lights per active line. For rasters of 825 and 1023 lines, the maximum output per active line is 300 and 250, respectively.

The point light generator receives and stores up to 2048 point light words from the point light orderer during the first part of each raster field. For each active line of the field, the point light generator determines which lights are active, and selects the highest priority light starting in each channel element for output to the video processors. The point light words are received in ascending element number order from the point light orderer. This order is maintained within the point light generator so that the point light words are transferred to the video processors in the same order.

Edge Generator. The edge generator currently receives and stores up to 1024 edge words from the Frame II face edge processor during the first part of each raster field period and can be expanded to 2048 edges. For each active line of

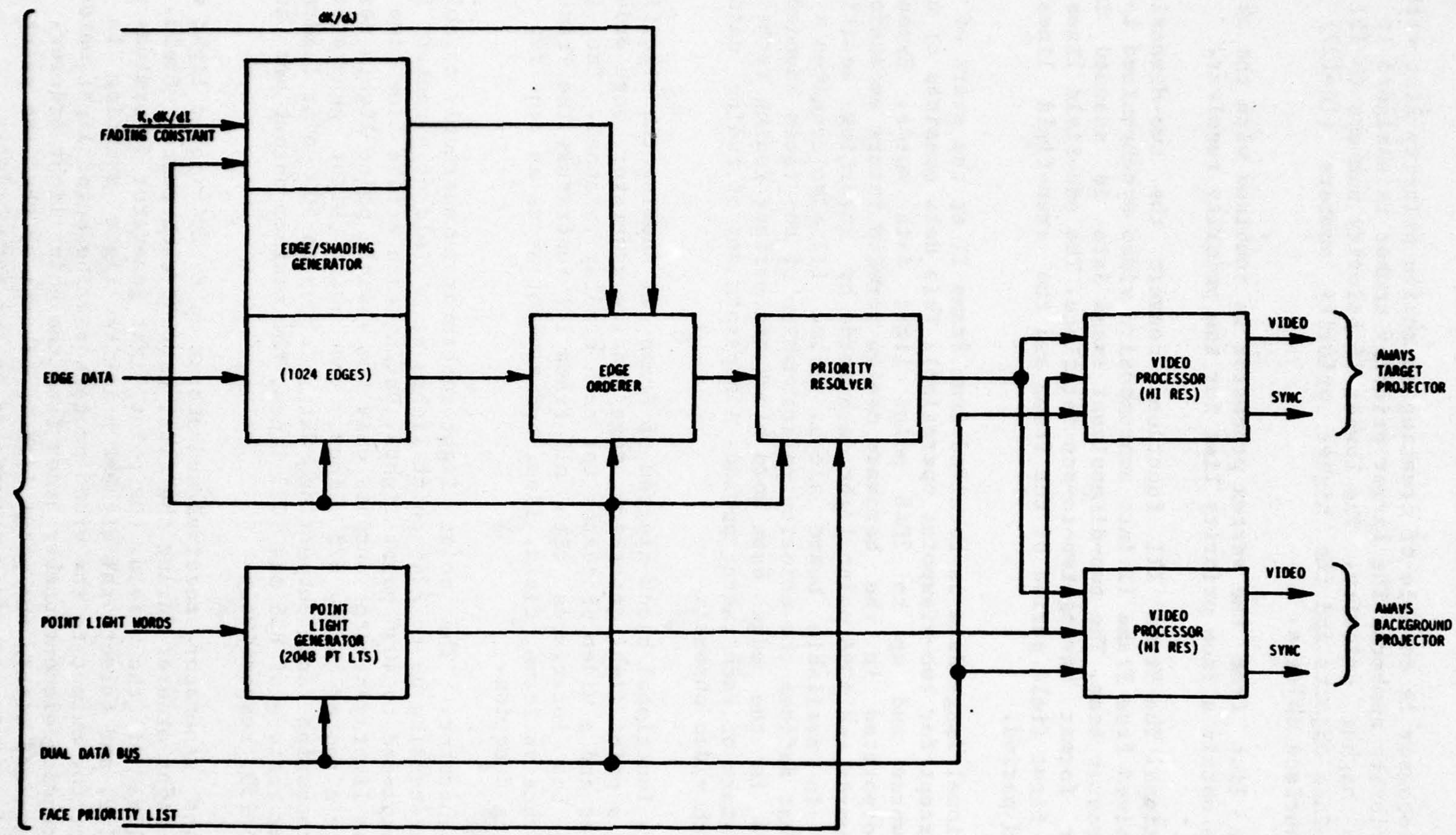


Figure 20. Frame III Function Block Diagram

the field, the edge generator determines which of the edges intercept the line, calculates the intercept with the line top and/or bottom for each of these edges, and outputs the intercept values to the edge orderer along with the edge word.

Scanning of the 1024 edge data words each line time is performed by four identical edge scanning functions with each scanner processing 250 edge words. The edge scanners select and store the addresses of the edge words that will be active for the next active line. At the same time, the edge generator computes the line intercepts for the active edges of the current line. For a raster having 525 lines, the edge generator is capable of processing and outputting data for up to 500 edges per active line time. For rasters of 825 and 1023 lines, the maximum output per line is 300 and 250 edges, respectively.

Shading Generator. The shading generator operates in parallel with the edge generator. During the first part of each raster field period, the shading generator receives, from the shading processor, and stores the shading data for up to 1024 edges (can be expanded to 2048 edges). For each active line of a field, the shading generator computes the shading modifier for the left intercept with the line of each edge intersecting the line. The shading generator processes data for up to 500 edges per active line time for a 525-line raster, and 300 edges or 250 edges for rasters of 825 or 1023 lines, respectively.

The shading generator receives the edge left vertex shading modifier (KS_L) and the shading modifier change per line along the edge (dKS/dI). The general experssion utilized in computing the left intercept shading modifier is:

$$KS(PR)L = KS_L + (dKS/dI)\ (I_{AL} - I_{LV})$$

where

KS_L is edge left vertex shading modifier

dKS/dI is shading modifier change per line

I_{AL} is active line number

I_{LV} is left vertex line number

The output edge data of the edge/shading generator is presented for horizontal keystone distortion correction. A linear mapping extrapolation is used to modify the value of each edge crossing on every raster line as a function of the raster line and horizontal distance from the screen center. This predistorts the image so that upon projection the keystone distortion is effectively removed.

The point light generator similarly presents the point light data for the same horizontal distortion correction.

Edge Orderer. The edge orderer currently receives and stores up to 1024 edge data words from the Frame II face edge processor during the first part of each field period and can be expanded to 2048 edge data words. For each active line

of the field, the edge orderer receives potentially visible edge count words from the edge generator.

The edge orderer orders the potentially visible edges of each system raster line by channel and within a channel group by the edge intercept with the line having the smaller element number. The ordered edge count words of each active line are supplemented by the stored edge data words for the same edges. The edge word from the edge generator contains an address with which the orderer reads the stored edge data. This data is transferred to the priority resolver along with the ordered edge data from the edge generator.

Priority Resolver. The priority resolver receives the potentially visible edges for each system raster line from the edge orderer, resolves priority conflicts between edges, calculates edge smoothing area weighting functions, and outputs the visible edges to the video processors. For any line element of a channel in which more than one visible edge begins crossing the line, the priority resolver selects no more than two edges to control the color transitions of the line at that point. Edge selection is based on priority relationships and edge smoothing characteristics. The priority resolver is capable of outputting two visible edges for a line element to a video processor.

The face priority list is received from the Frame II priority processor at the start of each frame period. The priority resolver stores the face priority list in face number order. During each active line interval, the priority resolver receives potentially visible edge words from the orderer, processes the edges, and outputs the visible edge words for the same active line to the video processors. As each edge is received, the face number from the edge data word is used to read the face priority list and obtain the relative priority number for the edge. The priority resolver maintains a list of the active priority levels for the line and compares the two highest active priority levels with the edge priority. Only edges of the two highest active priorities are considered as potentially visible edges.

For any given line element, the priority resolver selects the two best edges for each of the two highest active priority levels. It then selects the best two edges from these four edges as the visible edges. The best edge criteria are, in general, designed to select those edges having the most effect on the color of the line in the direction of increasing element numbers.

The visible edge word sent to the video processors contains up to three face colors and the resolution element area data for two edges. The priority resolver calculates the first element area to the right of the edge and the change-in-area per element for each edge. It also selects and transmits proper shading parameters to the video processors.

Video Processor. The two video processors compute the element color for each raster line element and output the color data to the AWAVS display system in analog video form. The video processors are identical and are individually assigned to process data for a single display channel.

In the current AWAVS application, only one of the two video processors is used to provide a single channel of black and white video output to the AWAVS target projector; however, the second video processor is operational and can be used to provide a second channel of video output. Although the current

application requires black and white video, both video processors can be expanded to provide full-color video in noncomposite red, green, blue form by installing circuit cards of existing design into available card slots.

Each video processor calculates the element colors for a given raster line during a single raster line time for display during the next raster line time. Color calculations are based on edge and point light colors, element areas subtended by edges and point lights, curved surface shading effects and fading effects for two dimensional surface faces. The video processors receive edge data and shading modifiers from the priority resolver in the form of edge data words. Point light data words are input from the point light generator and fading factors are input from Frame I at the beginning of each frame period.

Edge data words and point light data words are simultaneously applied to both video processors but the individual video processors will accept only that data that contains the number of the display channel to which the video processor is assigned. Each video processor can receive and store up to 256 edge data words and 256 point light data words during each line interval. Both the edge data words and the point light data words are received and stored in ascending element order.

Edge data influence in determining element color is calculated on the basis of edge crossings within the element, the element areas subtended by the edges, face colors contained in edge data words and background color.

For this calculation, each element is considered to be influenced by three colors; first edge color (C1), second edge color (C2) and background or contiguous face color (C3). The resulting element color is calculated by means of an algorithm in the following general form:

$$\text{Element Color Edge} = A1\ (C1) + A2\ (C2) + [1 - (A1 + A2)]\ (C3)$$

where

A1 and A2 Element areas subtended by edges 1 and 2, respectively.

The edge colors input to the element color calculation are modified for curved surface shading effects on a per element basis. This is accomplished by means of a shading modifier (K_{SL}) and a change in shading modifier per element value (dK/dJ) contained in edge data words for curved surfaces. The shaded element color is computed in accordance with an algorithm of the following general form.

$$\text{Element Shaded Color} = C \left[K_{SL} + \sum_{1}^{n} (dK/dJ) \right]$$

For the first element of the edge, the color (C) is multiplied by the shading multiplier (K_{SL}). Subsequent element colors are modified by adding the change in shading multiplier value (dK/dJ) to the previous element shading modifier.

Each element color computed from the edge data is subsequently modified as required by the surface fading function. This function is only applied to edge data for two-dimensional surface features. Fading for nonsurface three-dimensional models and point lights is performed by the color processor in Frame II. The surface fading function is implemented on the basis of an object/surface flag within the edge data word that identifies the edge as a

surface feature edge. The faded element color is calculated by means of an algorithm in the following general form:

Faded Element Color = F (Haze Color) + (1 - F) (Element Color)

where

F is a fading coefficient computed from the fading data received from Frame I.

The faded element color is combined with point light element color to obtain the final element color output to the display system.

Point light data influence in determining element color is calculated on the basis of data contained in point light data words received from the point light generator. The data includes light color; a size code that indicates the number of elements subtended by the light; three area terms (first element area, middle element area, and last element area) that define element areas subtended by the light, a light priority code that defines the priority level of the light with respect to edge data in the same raster line element and an element number that defines the first element wherein the light becomes active. Point light element color is calculated by multiplying the appropriate element area term (ALF, ALM or ALL) times the point light color.

In calculating the combined effect of point light and edge colors on the final element color, the video processor compares the point light priority flag with the edge data word priority flag to determine if point light color is to be used. If the point light priority is less than the edge data priority, point light color is not used. If the point light priority is equal to or greater than the edge data priority the point light color is combined with edge color by means of the following general algorithm:

Combined Element Color = A_L (Light Color) + (1 - A_L) (Faded Element Color)

where

A_L = appropriate light element area (ALF,ALM or ALL).

The combined element color for each line element is stored in an output memory for access during the following line interval. During the next line interval, the element color data is read from memory at the system element rate and converted to analog video by digital-to-analog converters.

SUPPORT FUNCTIONS

MASTER TIMING. The master timing function provides the overall timing and synchronization signals for synchronizing operation of the visual system. In general, these signals are the basic logic clocks used in the image processor and television raster scan timing and synchronization signals used by the general-purpose computer, image processor and operator console television monitors.

The master timing function controls the rate and period of computation cycles of all real-time image generation functions and provides individual sets of synchronization signals for three television raster scan rates; 525, 825 or 1023 lines.

The master timing function sends the general-purpose computer two 30 Hz raster field interrupts, end odd field and end even field. The general-purpose computer uses both interrupts to synchronize Frame I operations at a 60 Hz field rate.

Starting and ending synchronization signals for odd and even raster fields are sent to all image processor functions to synchronize field and frame rate processing functions at the selected line resolution rate. In addition to field synchronization signals, Frame III functions receive line syncs to control computation cycles that operate at the raster line rate and the video processors receive an element clock.

The master timing function also generates horizontal and vertical syncs and composite blanking syncs for the AWAVS display system and operator console CRT monitors.

Data Bus. The image processor data bus provides the data links between the PDP-11/T55 general-purpose computer and all functions within the image processor. Two identical data buses A and B, provide half-duplex data transmission between the general-purpose computer interface terminals and standard data terminals at various locations within the image processor. Sixteen-bit data words are transmitted bit-parallel and word-serial, in a variable length block using PDP-11/T55 DR11-B interfaces for general-purpose computer direct memory access.

Manual data entry and display of bus data is provided for noncomputer or off-line data transmission by the display and data entry panel interface.

Display and Data Entry. The display and data entry function provides the capability via an indicator and control panel to manually interact with data bus A and B. As such, the panel provides a means for manual entry of specified data and commands into or the readout of selected data and commands from the various image generation functions in the image processor for maintenance and diagnostic purposes. It is similar in design and purpose to the standard maintenance panel found in any general-purpose computer. The panel configuration is illustrated in figure 21.

Internal Computer Interface. A computer interface terminal provides the interface between the PDP-11/T55 DR11-B interfaces, and the image processor data buses. The terminal provides the controls and timing to maintain synchronous data transfers in either direction between a DR11-B and a image processor data bus.

All data transfers are initiated by the DR11-B under program control. The DR11-B is a general-purpose, direct memory access interface to the PDP-11/T55 unibus. It is capable of performing variable, block-size data transfers without program intervention after program controlled initialization. Operation under program control is initialized by loading the word count of the number of transfers, the initial unibus address where the block transfer will start, and the function code identifying the type of transfer to be

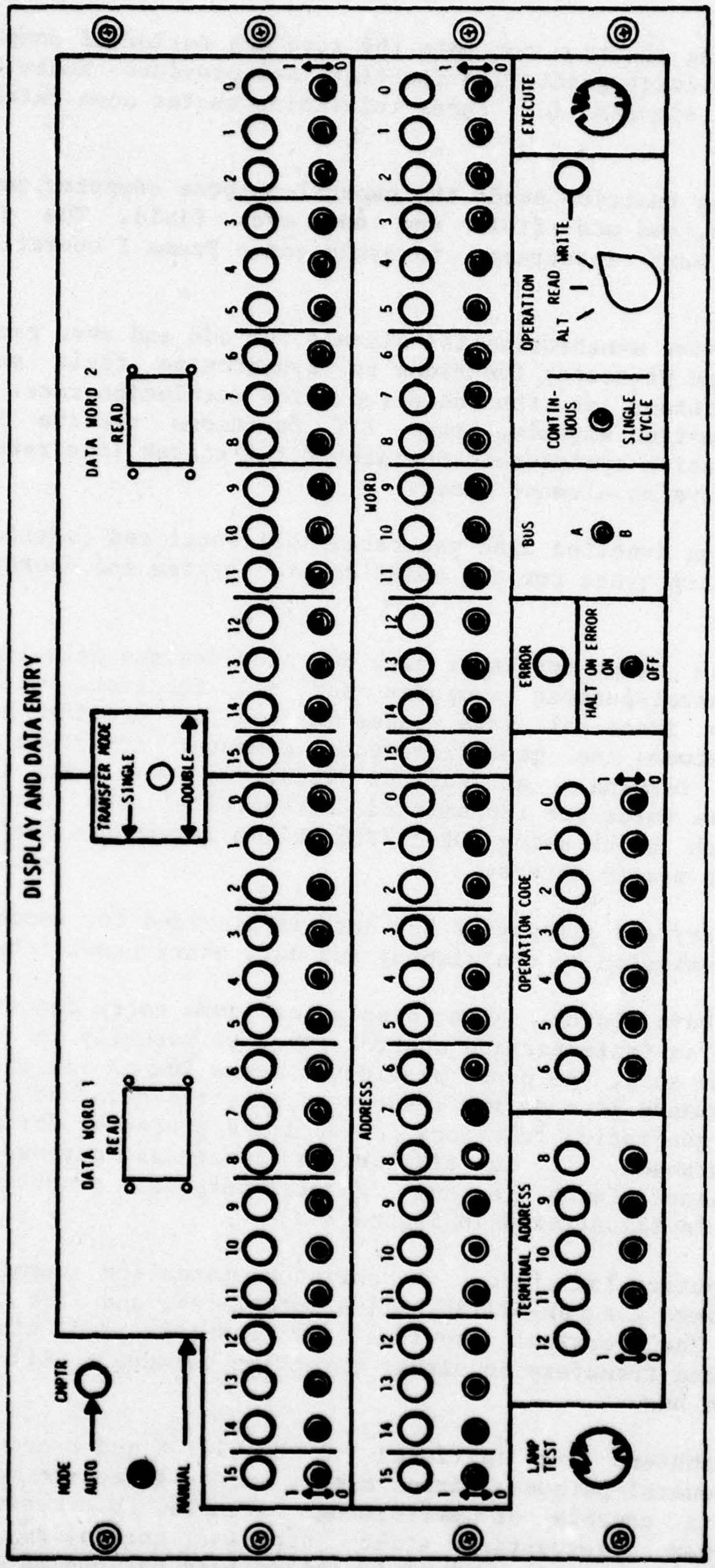


Figure 21. DDE Control Panel

performed. The DR11-B interface controls allow the interfacing device to control the rate of data transfer until the specified number of words are transferred.

The interface between each DR11-B and associated computer interface terminal consists of 16 data-out lines from the DR11-B, 16 data-in lines to the DR11-B, three function control lines from the DR11-B, and data transfer synchronizing controls.

AWAVS SIMULATION COMPUTER INTERFACE. The AWAVS Visual System is interfaced to the AWAVS simulation computer through a DR11-B interface unit in the Image Generation Subsystem general-purpose computer. The data transferred from the AWAVS simulation computer includes the following:

a. Simulator aircraft position, attitude and motion rates

b. Moving models position and attitude

c. Environment selection and control information

d. Target projector attitude and zoom lens data.

The data transferred from the PDP-11/T55 back to the AWAVS simulation computer includes the following:

a. Data error diagnostic information
b. CIG collision detection status
c. CIG operating status

Data block transfers from the AWAVS simulation computer to the AWAVS Visual System occur at a 30 Hz rate which coincides with the visual system television raster frame rate.

DATA BASE GENERATION FUNCTIONS. The AWAVS Data Base Generation Facility facilitates user development of training mission or experimental visual data bases for processing and display by the AWAVS real-time image generation equipment or by the camera station. The data base development process is basically divided into two levels of activity; modeler activity in developing data base input data and data base generation software activity which compiles input data into a functional data base. Figure 22 illustrates the data flow within the Data Base Generation Facility and the interface medium by which new data bases can be displayed via the Image Generation Subsystem.

Modeling activity is largely an iterative process whereby the modeler defines the environment area to be displayed, systematically develops the objects and models to be displayed and orients the objects/models in the environment scene. Typical references used in modeling visual display data bases are photographs, maps, scale models and moving picture films of real world environments. To model such real world environment scenes requires knowledge of the real-time CGI scene generation hardware capabilities and limitations, composition and format of object, model, and environment data inputs, overall modeling rules and constraints and operational characteristics of the data base generation software programs. These data and other modeling guidelines are presented in Volume V of the AWAVS Programming and Math Model Report entitled "Aviation Wide Angle Visual System Modeling Guide."

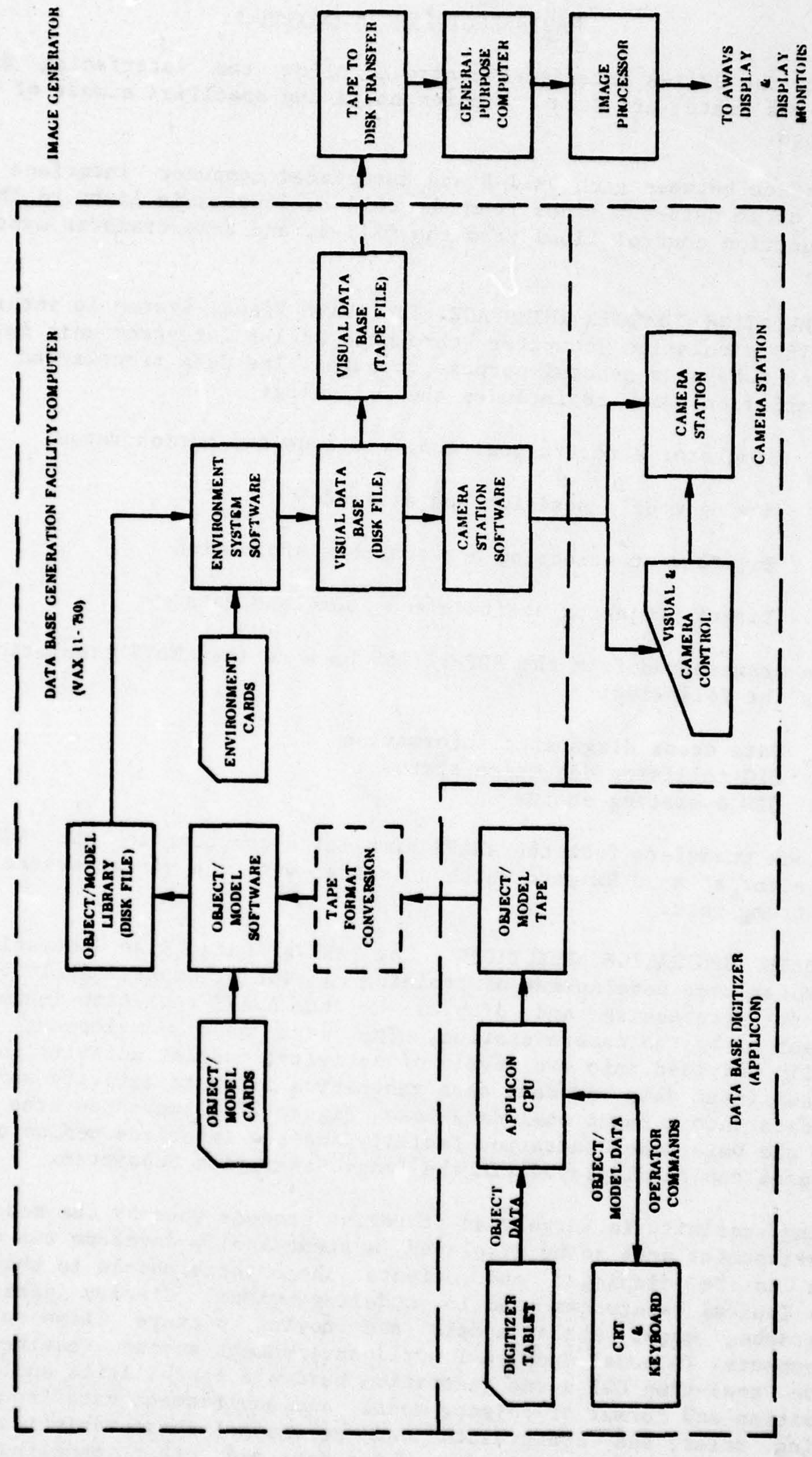


Figure 22. Data Base Development Facility and Camera Station Data Flow

Some of the basic modeling procedures are presented here as an aid to describing the functions of the data base generation facility and data base generation software.

Based on current environment storage capabilities of the real-time scene generation hardware, data bases are typically defined for a 200 nautical mile square gaming area identified as an environment set. The gaming area may be divided into sixteen 50-nautical mile squares identified as environment data blocks. From any viewpoint within the gaming area a maximum of 9 environment data blocks are active (or within viewable range).

The environment scene is composed of two-dimensional and three-dimensional static models and may contain three-dimensional moving models that move about in the environment. The two-dimensional static models are used to describe flat surface features such as ground culture or runway patterns. The three-dimensional static models are used to describe three dimensional cultural features such as an airport building complex.

In the modeling process both two-dimensional and three-dimensional models are constructed from objects which are basic geometric figures defined by the modeler. A single object may contain up to 16 convex planar faces each of which is defined by at least three vertices. The object formed by these faces must also be convex.

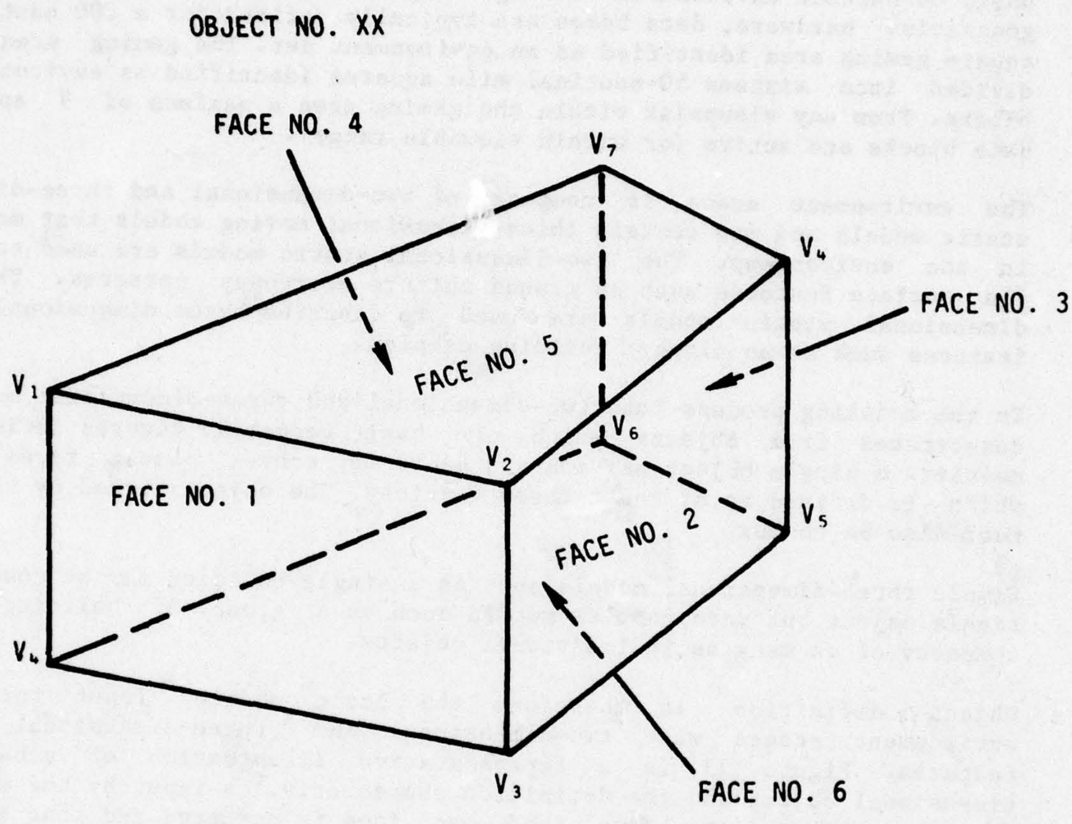
Simple three-dimensional models such as a single building may be composed of a single object but more complex models such as a group of buildings may be composed of as many as 16 individual objects.

Object definition is therefore the basic modeler input for defining environment scenes with two-dimensional and three-dimensional cultural features. Figure 23 is a representative illustration of a basic three-dimensional object and the definition characteristics input by the modeler to describe the object. Note that each face is numbered and that each vertex defining the full extremities are numbered in clockwise fashion when viewed from the visible side of the face. Examples of the types of data a modeler would input to describe the object are:

a. Unique object name (alphanumeric designator)
b. Object type designation (3-dimensional or 2-dimensional)
c. Number of vertices
d. Number of faces
e. Face data (numbers, defining vertices and color)

There are two methods for inputting object data to the data base generation facility computer in constructing a visual data base. Using the first method, object data is created manually and input via punched cards. Using the second method, object data is created at the digitizer station and input via magnetic tape. Object data thus entered is processed by the Object Software system and stored in an object library for subsequent access in constructing models.

The second step in the modeling process is the definition of models in terms of type, object composition, levels of detail at various view ranges, size, orientation and priority. The model definition process provides the modeler with several flexibilities in defining model characteristics. For example, models constructed from the same object data can be displayed at 8 different



FACE 1 DEFINED BY VERTICES V_1, V_2, V_3, AND V_4 + COLOR
FACE 2 DEFINED BY VERTICES V_2, V_4, V_5, AND V_3 + COLOR
FACE 3 DEFINED BY VERTICES V_4, V_7, V_6, AND V_5 + COLOR
FACE 4 DEFINED BY VERTICES V_7, V_1, V_4, AND V_6 + COLOR
FACE 5 DEFINED BY VERTICES V_1, V_7, V_4, AND V_2 + COLOR
FACE 6 DEFINED BY VERTICES V_3, V_5, V_6, AND V_4 + COLOR

Figure 23. Model/Object Definition Characteristics

levels of detail by varying the object content. Likewise, dimensional data for objects contained in the object library can be rotated or multiplied to achieve the desired model configuration. Model data is entered into the data base generation facility computer by means of keypunch cards or magnetic tape from the digitizer station and is processed by the model software system. The model software system produces a model library file and a model directory file which are subsequently accessed by the environment system software to retrieve model data in structuring an environment data block.

The third step in the modeling process is the definition of environment data blocks which comprise the total environment data set. Typical input data required to structure an environment data block includes:

a. Unique data block name

b. Identification of models to be included in data block including model level of detail

c. Coordinate set identification

d. Environment model orientation coordinates

e. Special codes for sum angle illumination, curved surfaces and model face color blending

f. Exception data to modify model/object definition characteristics

These data are entered via keypunch cards and are processed by the environment system software to produce environment data blocks and a complete environment set data base. The data base is recorded on a magnetic disk in the format required for access by the Image Generation subsystem.

The environment data block system consists of an executive control program and subprogram routines. The executive program provides an operator dialog and systematically calls each of the subprogram routines to process environment data input via keypunch cards. The resulting output from the environment data block system processing is a complete environment data block recorded on an environment set disk on the format required for processing by the camera station software system and the Image Generation subsystem. The system executive also provides error messages at the operator's data entry console to identify input card errors and enables the operator to request summary listings of data included in the environment data block.

CAMERA STATION FUNCTIONS. The Camera Station and camera station software executed by the VAX-11/780 computer enables the user to produce polaroid or 35 mm film photographs of environment data base scenes. The camera station is a high performance cathode ray tube (CRT) film recorder capable of producing black and white or color photographs of digitally encoded pictorial data. The camera station software processes the environment data by emulating the image processing functions performed by the real-time image generation subsystem and outputs digitally encoded television raster element data to the camera station on a line by line basis.

The camera station software programs and the environment data base are both recorded on a magnetic disk. Through a series of operator commands the user can initiate the camera station software, select the area of the data base to be processed, specify viewpoint and visibility conditions for the selected scene and select one of three television raster display resolution rates for the photographic image.

The camera station plots raster line data by means of a multiple resolution plotting matrix composed of individually addressable picture elements (pixels). The high, medium and low resolution matrices are composed of 4096 x 4096, 2048 x 2048 and 1024 x 1024 pixel matrices, respectively. In accordance with the resolution rate selected by the operator, the camera station will plot each raster line element as a single pixel in the selected pixel matrix.

The camera station also provides a set of program selectable filters; that includes red, blue, green and neutral filters. The netural filter is used for black and white photographs and the three primary color filters are used for color photographs. For color film exposures, the pixel matrix is scanned three times; once with each of the three color filters selected. For each scan, the camera station software outputs a separate element color word that specifies the intensity the color being processed.

A moving picture sequence of the environment scene can be created by exposing sequential frames on 35 mm film in accordance with a program selectable motion rate for the viewpoint or moving models viewed from a single viewpoint.

SECTION IV

ADVANCED TECHNOLOGY FEATURES

GENERAL

This section provides individual descriptions of new technology features incorporated in the AWAVS. Each feature is described in terms of concept and actual hardware or software implementation.

TWO-VIEWPOINT CAPABILITY

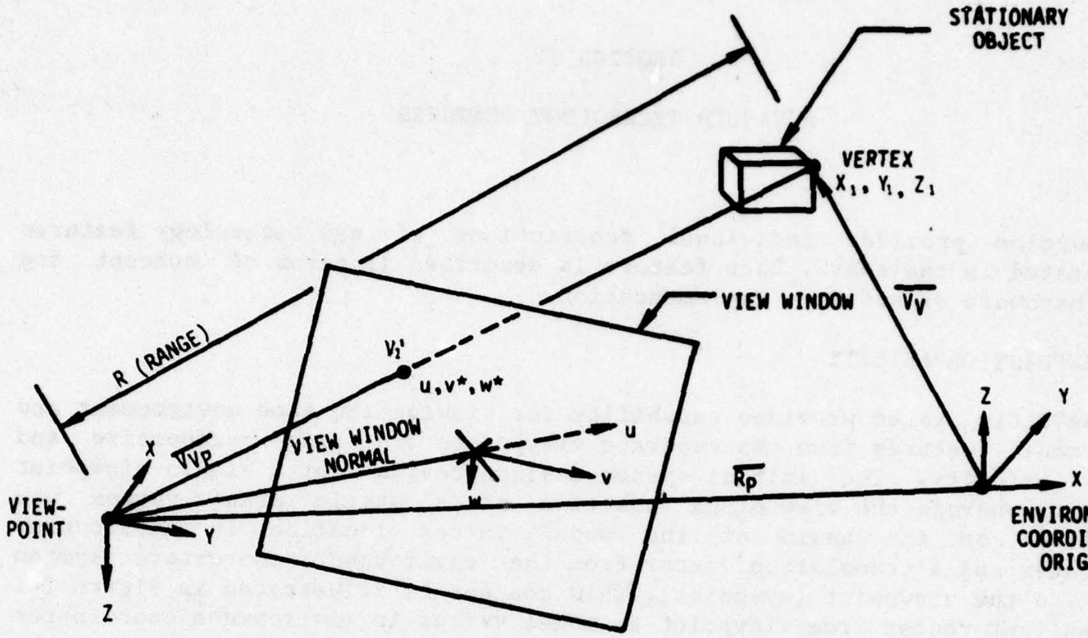
The AWAVS CIG system provides capability for viewing the same environment and moving model features from two separate viewpoints in true perspective and correct priority. The initial system design provided for a single viewpoint capability wherein the view plane position of a static model vertex was calculated on the basis of the model vertex location in environment coordinates and a translation vector from the environment coordinate system origin to the viewpoint (eyepoint). This concept is illustrated in figure 24. The resultant vector from viewpoint to model vertex in environment coordinates is range normalized by dividing the components of the resultant vector by the calculated range from viewpoint to the model vertex. This range normalized resultant vector is then rotated from environment coordinates to viewpoint coordinates by multiplying the range normalized vector by a direction cosine matrix to identify the u, v* and w* view window coordinates of the model vertex. The algorithms for implementing this vector transformation are shown in figure 24.

To implement a two viewpoint capability in the AWAVS CGI system the vector transformation process just described is performed for two viawpoints which results in two range normalized viewpoint to environment origin vectors rotated to viewpoint coordinates. These two viewpoint vector transformations are performed during alternate television raster display field times. Subsequently the two viewpoint vectors are independently applied to each element of environment and moving model data to provide separate object/model level-of-detail, channel assignment and priority relationship determinations for the two viewpoints. This results in two viewpoints being updated at a 30-Hz rate.

The implementation method employed in adding this capability provides the flexibility of displaying only one viewpoint in the two AWAVS display channels or of assigning the two viewpoint displays to separate display channels. The two viewpoints may be different views of the same data blocks or completely independent views of two totally separate and unique data blocks.

MACH BAND MINIMIZATION

The Mach band improvement was incorporated in the AWAVS design to minimize abrupt color changes that might occur as the viewpoint approaches environment features whose colors are faded as a function of range from the viewpoint. Haze and fog visibility features are accomplished in the image processor by



1. $(\overline{V_{VP}})_{xyz} = (V_{V_X} - R_{P_X})\bar{i} + (V_{V_Y} - R_{P_Y})\bar{j} + (V_{V_Z} - R_{P_Z})\bar{k}$

2. $R = \left[(V_{V_X} - R_{P_X})^2 + (V_{V_Y} - R_{P_Y})^2 + (V_{V_Z} - R_{P_Z})^2\right]^{1/2}$

3. $\frac{\overline{V_{VP}}}{R}$ = RANGE NORMALIZED VIEWPOINT TO VERTEX VECTOR IN ENVIRONMENT COORDINATES

$$= \frac{(V_{V_X} - R_{P_X})\bar{i}}{R} + \frac{(V_{V_Y} - R_{P_Y})\bar{j}}{R} + \frac{(V_{V_Z} - R_{P_Z})\bar{k}}{R}$$

4. ROTATE $\frac{V_{VP}}{R}$ IN ENVIRONMENT COORDINATES TO VIEW WINDOW COORDINATES

$$\left[W_i\right] \underset{VW}{\overset{ENV}{\downarrow}} \cdot \frac{V_{VP}}{R} (X, Y, Z) = \frac{V_{VP}}{R} (U, V^*, W^*)$$

WHERE

$\left[W_i\right] \underset{VW}{\overset{ENV}{\downarrow}}$ IS A STORED DIRECTION COSINE MATRIX FOR EACH VIEW WINDOW THAT ROTATES A VECTOR IN ENVIRONMENT COORDINATES TO VIEW WINDOW COORDINATES

Figure 24. Vector Transformation

fading the color of displayed images toward a common fog color as the images approach the horizon. Fading calculations are performed as a function of range from the viewpoint aircraft by means of the following nonlinear fading function:

$$\text{Fading (F)} = e^{-1/R_f}$$

where

> R_f is proportional to 1/Range x Fog Density; Range is range from viewpoint to environment feature; and Fog Density is an operator selectable variable.

Implementation of this function causes color fading to range from no fading for features at near distances to total fog color at the horizon.

Under most conditions the discrete changes in feature color that occur as the viewpoint approaches the object are sufficiently small (less than 1 percent) that no Mach band effect is perceivable. Under certain visibility conditions and in cases involving high-contrast feature colors; however, stepped color changes of 5 percent could occur using the initial AWAVS CGI Visual System design criteria. The potentially abrupt color changes were the product of limited resolution of the R_f value. In the initial design, R_f resolution was limited to 10 bits, thus a single bit change in the R_f value could cause a 5-bit change in the fading (F) value.

To improve the precision of the fading function calculation, R_f value resolution has been increased to 13 bits. This limits the rate of F value change to 1 bit per step change in R_f value and thereby reduces color changes due to fading calculations to no more than 0.5 percent.

Under certain low intensity color conditions, Mach bands may be visible but the threshold at which they are first perceived has been lowered. Since the maximum fading calculation accuracy is carried through the video processors up to the output memories, the video processors can be modified in the future to provide 12-bit output resolution and thereby totally eliminate Mach band effects.

FACE LEVEL OF DETAIL AND BLENDING

The level of detail function as initially defined for the AWAVS CGI Visual System is a function whereby the amount of detail (edges and faces) displayed for a given model is reduced in true perspective form as functions of range from the viewpoint to the model and model size. The method of implementing the function involves storing model face, edge and vertex data for several levels of detail in the environment memory. The appropriate level-of-detail for a given model image is calculated at the update rate as a function of viewpoint range from the model. As the viewpoint approaches the model, the model level-of-detail is increased in incremental steps until the model is displayed at its highest level of detail.

Several deficiencies noted in implementing this approach to level-of-detail processing include large changes in edge computation requirements as level-of-

detail changes, the apparent breakup of small faces and distraction of sudden appearances of new features in the environment scene.

To eliminate these difficiencies two major improvements have been implemented in the AWAVS CGI Visual System design; face level-of-detail processing and face color blending.

Following model level-of-detail processing, each face of a given model level-of-detail is also processed for level-of-detail. The level-of-detail at which a face is displayed is determined as a function of face size and orientation from the viewpoint. Faces which subtend an area less than or equal to the size of a display resolution element can be eliminated from further processing thereby reducing abrupt changes in edge computation requirements as model level-of-detail changes occur. Eliminating small faces also reduces the deterioration of edge smoothing effects caused by faces with areas that approximate the size of a resolution element.

The method of implementing face-level-of-detail processing is similar to the two-dimensional model level-of-detail processing with modifications to account for faces orientations in other than the x-y plane.

The face blending function is incorporated in the design to reduce the effect of abrupt changes in model level-of-detail and to improve the overall display quality for small faces. The function is implemented by fading face color toward a specified background color as a function of face range from the viewpoint. In conjunction with the level-of-detail processing for each face, a color interpolation value is calculated to designate the percentage of true face color to be mixed with a background blending color. The net result of this feature is that distant faces are blended into the background and become more distinct as the viewpoint approaches the faces.

INCREASED SCENE COLORING

The increased scene coloring feature is incorporated in the AWAVS CIG Visual System to implement recent developments for improving scene realism and to avoid restrictive limitations of the number of colors available for point light applications. The initial design baseline for the AWAVS provided 64 separate colors or gray shades for coloring object and surface faces and 16 separate colors for coloring point lights. Black and white video scenes are currently specified with capability to expand the design to full color. The increased scene coloring feature provides 256 separate colors for object and surface face coloring and 256 separate colors for point light coloring. Recent experience gained from commercial applications of similar full-color CIG systems has proven that the additional face color capability creates a marked improvement in scene realism by providing more subtle variations in surface texture and terrain features. The additional point light coloring capability eliminates restrictions in point light applications for dusk scenes wherein both day and night scene applications of point lights must be combined.

ACTIVE FACE LIST EXPANSION

The Active Face List memory within the Vertex Processor function stores data for all active faces displayable in both channels during a single display cycle. The initial AWAVS design configuration limited the memory's capacity to face edge data and point light data assigned to 512 active faces. This

limitation is not restrictive in terms of current AWAVS display requirements; however, it will restrict system capability for displaying complex data bases if the number of channels, edges, or point lights are increased in the future.

The improved Active Face List memory design provides capacity for independent storage of 512 active object/surface faces and 512 active point light faces. The improved design further expands storage capacity by modifying the method for storing face data that is active in more than one channel. In the initial design, faces that became active in two channels were entered in the memory twice. In the improved design, channel assignment controls have been modified such that faces active in several channels will occupy a single entry in the Active Face List.

INCREASED POINT LIGHT EXPANSION

The increased point light generation capability is incorporated in the AWAVS image generator design as an expansion capability to avoid future restrictions in displaying complex data bases and to improve point light applications for motion cues. The expansion improvement also relieves potential restrictions in displaying dusk scenes which require both day and night applications of point lights.

The initial design configuration provided point light generation capacity for 2048 point lights. The improved design provides capability for expanding point light capacity to 4096 point lights by the insertion of additional, existing design logic boards.

ACTIVE EDGE EXPANSION

The initial design configuration for the image generator provided capability for generating and displaying 1024 edges distributed between two display channels. This capacity was adequate for initial AWAVS display requirements; however, it became restrictive in terms of scene density as data base detail increased.

Improvements incorporated in the current design configuration have permitted expansion of the system from a 1024-edge capacity to a 2048-edge capacity by inserting additional circuit boards. The basic improvements consist of modifications for expanded memory addressing, additional backplane circuit board slots, cooling and power. The additional area for future growth has been achieved by implementing the latest technology in integrated circuit design and high-density component packaging.

DISTORTION CORRECTION

A recently developed technique for dynamically predistorting the computed image has been incorporated in the image generator design to compensate for the horizontal keystone distortion that results from projecting a flat screen image onto the AWAVS spherical display surface. The correction reduces the area of interest projector distortion and is accomplished in a manner that dynamically updates the correction process as a function of projector pitch angle.

The algorithm implemented is a linear mapping extrapolation that modifies the value of each computed edge crossing for every raster line as a function of the raster line being computed and the horizontal distance from the top or bottom of the display screen. The general-purpose computer calculates real-time correction constants based on projector pitch angle and transmits three constants per channel to the image generator for dynamics updating. This simplifies dynamic tracking and update to insure that distortion correction is accurate for all projector rates.

For true area of interest projected scenes in which the object being viewed is near the center of the screen, the linear mapping technique imposes no special boundary conditions. For scenes in which the computed images extend beyond the field-of-interest boundaries, the computed field of view is first expanded as a function of camera pitch angle and is then assembled as a function of the linear mapping constraints. This ensures that the transformed mapping does not create a foreshortened right-hand boundary that would allow unterminated faces on the right side of the screen.

EXPANDED POINT LIGHT CONTROLS

Another new feature incorporated in the AWAVS image generation design is the expansion of point light controls to provide more flexibility in data base modeling applications of lights as both lights and daylight surface texture patterns. The feature is implemented by adding controls that permit programming limits and rates of change curves for light sizes.

In the initial design configuration, point light size was permitted to grow uniformly from a minimum of one element by one raster line to a maximum of seven elements by seven raster lines as a function of diminishing range. The expanded point light controls add two codes to data processed for each point light. The first specifies the minimum light size and the second specifies maximum light size. In addition, the off-line data base generation software has been modified to permit the modeler to select a rate of size change curve for each point light.

The size limit codes and rate of size change curves can be used effectively in the data base modeling function to expand the application of point lights and achieve more realistic visual cues.

The point light parameter memory was also increased to 256-parameter sets to provide sufficient special light controls and functions for complete utilization of all 4096 point lights in the fully expanded system.

COLLISION DETECTION

The collision detection feature permits detection of collision of the simulator aircraft with terrain features or surface models. The feature is implemented by defining an envelope that surrounds the simulator aircraft in three-dimensional space and is dynamically oriented to coincide with the simulator aircraft position and attitude. During simulated flight, the envelope is tested against active data base terrain and model features to determine if any portion of the envelope penetrates an object or model in the environment. If such penetration is detected a collision detection signal is transmitted to the general-purpose computer which reports the collision to the system operator.

The collision detection feature is incorporated as an operator selectable option. When activated, the feature occupies one channel of edge processing time thereby restricting the upper limit of AWAVS visual display capability to four channels. With collision detection deactivated the display capability can be increased to five channels.

DATA BASE FEATURE IDENTIFICATION

The special-purpose Image Generation hardware now provides the necessary logic to isolate and identify individual data base features (faces, point lights, objects, and models) based on their projection on the display window. This feature, when used in conjunction with the Update Environment Modeling software described in paragraph 2-7, permits real-time, interactive data base analysis and modification.

When the Update Environment Modeling software is active, a raster line pointer appears on the screen and can be manipulated by means of console positioning commands or joystick movement. When the tip of this pointer is located over a feature of interest, the modeler can request a summary of the pertinent data describing that feature. The "hooks and handles" provided by the special-purpose hardware that enable the software to trace the feature back to its origin in the environment data base include:

a. Data block address of model
b. Environment model number
c. Level of detail for model
d. Environment face number
e. Environment point light number/face
f. Active model number

Using this advanced technique the modeler may currently edit the data description (e.g., change face color, critical dimension, shading flag, etc.) and additional software would ultimately permit major data base alterations including object/model translation, rotation, magnification and deletion.

ADVANCED SOFTWARE DESIGN FEATURES

The real-time image control software and data base creation software provided with the AWAVS CIG Visual System implement several advanced programming techniques which are described in following paragraphs.

AWAVS REAL-TIME (ART) SOFTWARE MULTITASK STRUCTURE

The ART software system is executed by the Digital Equipment Corporation (DEC) PDP-11/T55 general purpose computer in the Image Generation Subsystem and operates under control of the mapped version of the DEC RSX-11M V3.0 operating system.

The ART software system is composed of four functional tasks and one shared data area. The four functional tasks are the Operator Interface Control (OIC) task, the Visual Image Processing (VIP) task, the Data Base Update (DBU) task and the External Interrupt Control (EIC) task. The shared data area is

identified as the Common Data (DAT) task. Descriptions of the tasks are provided in paragraph 2-7 and the hierarchial arrangement of the system is illustrated in figure 6. The multitask, hierarchial arrangement and modular construction of the system enhances software development and modification and provides a priority related redefinition of processing flow during worst case processing loads.

Automatic Scene Initialization. The OIC task enables an operator to call an entire series of commands from special command files by means of a single input command at the operator DECwriter keyboard. Using this feature, the operator can load a data base, establish a fairly complex set of visual effects and conditions and initiate visual scene processing with a single command. The current special command files contain a fairly comprehensive set of command combinations; however, the existing files can be readily modified or new files can be readily created to provide additional command combinations. The command files are written in simple ASCII text format and can be modified or created by means of the system card reader or text editor (EDI) program.

Dynamic Data Base Update. The dynamic data base update task is responsible for loading environment data base data into the image generation hardware environment memory and provides an expanded capability for managing dynamically updated transient data bases as well as permanent data bases. Permanent data bases are modeled in a monolithic fixed environment structure and are not updated after being loaded into the hardware environment memory. Transient data bases are modeled in environmental data blocks that are loaded into hardware environment memory on the basis of range from the simulator aircraft viewpoint. The data base update task monitors aircraft viewpoint and initially loads only those environmental data blocks within a given range from the aircraft viewpoint. The data base update task continuously monitors aircraft viewpoint location and updates the data in environment storage with new environment data as the aircraft viewpoint moves within a predetermined range of the new data. The dynamic data base update concept therefore improves the efficiency of environment core storage utilization and essentially eliminates gaming area limitations posed by permanent storage of an environment data base.

Real-Time Control Path Redefinition. Another programming strategy employed to ensure visual image continuity involves a dynamic redefinition of program flow within the Visual Image Processing (VIP) task during peak processing loads. Activities within the task are divided into two categories: those essential to image continuity and those not essential to image continuity. During peak image processing loads, the task performs the essential activities first and interrogates a programmable cycle timer to determine if sufficient time remains to perform the nonessential activities. If insufficient time remains, the nonessential activities are eliminated. This technique assumes that worst-case processing loads are transient phenomena; therefore, the activities not related to image continuity are only eliminated during unusually large processing loads.

Data Base Dependent Processing Routines. The AWAVS software system has been designed to process only those control values required for coordinate systems active in the data base currently being processed whereas predesessor systems were designed to always process control values for the worst case number of coordinate systems that could be included in a training mission data base. The

new approach improves system performance statistics based on the average rather than worst case data base processing loads and provides a dynamic redistribution of major task processing loads based on current data base processing requirements. A major advantage of this approach over a system designed for worst case processing loads is that task loads can be distributed to accommodate user software experiments that would not be possible under a system whose task performance cycles are inflexible and constrained to worst-case processing.

System Execution Performance Report. In response to user request, the ART system will provide a system performance report printout on the line printer that permits the user to plot the execution times of the major ART tasks and the time required for task switching. The performance report is developed by means of an internal function that monitors ART system execution speeds at several key points in three of the four major processing tasks and accumulates timing statistics for each processing function. Representative statistics provided in the report include measured maximum, minimum and average time requirements and cycle requirements for each subtask. This overview of ART task time and cycle requirements provides a useful tool for user analysis of system performance characteristics under various processing loads.

Expanded Command Repertoire. The ART system design has been expanded to respond to more than 46 operator commands entered via the operator DECwriter terminal. New capabilities implemented by these commands include the following:

a. Ability to assign or remove joystick control of simulator aircraft viewpoints and all of the first three major moving model coordinate systems.

b. Ability to move simulator aircraft viewpoint through the environment under control of either a simple flight dynamics algorithm or a special data base inspection dynamics algorithm.

c. Ability to suppress system verification responses to commands entered at the DECwriter terminal to expedite system initialization and operation.

d. Operator selection of low (525-line), medium (823-line) or high (1023-line) video resolution rates.

e. Independent operator selection of level-of-detail control constants for each data base coordinate system.

f. Direct operator control over viewpoint and video processor display channel assignment.

g. Operator control over sun angle and sun/ambient illumination ratio constants.

h. Operator control of collision detection origin offset and vector dimension parameters.

i. Operator control of flight path recording and playback for real-time training debriefing and automatic film production at the camera station.

j. Independent operator control over definition and application of display distortion correction parameters for both video display channels.

DATA BASE CREATION SOFTWARE

One of the most significant advances in the AWAVS CIG Visual System software design is a set of data base generation software that enables the user to develop real-time data bases at a separate data base generation facility to avoid sacrificing real-time mission simulation time on the Image Generation subsystem. The data base creation software is executed by the DEC VAX 11/780 general-purpose computer in the data base generation facility and provides total capability for developing and recording data bases for real-time display via the Image Generation subsystem.

The most significant design advance incorporated in the data base creation software is the structure of data base peripheral storage format. Earlier CIG systems used a single core image file for peripheral storage which required file allocation to allow for worst case data loads. In the AWAVS design, this approach was abandoned in favor of a more efficient data base storage concept that uses a hierarchial cluster of disk file modules. Figure 25 illustrates the hierarchial arrangement of the disk files.

Principal advantages of this concept are:

a. Peripheral storage requirements are minimized by using only as much space as is required by the actual data. This improves the efficiency of storage space utilization and significantly expands total storage capability beyond that provided by the monolithic core storage concept used in earlier CIG systems.

b. Data storage formats are designed such that the ART system can efficiently initialize and update individual environment data blocks.

c. The multifile structure permits fast, modular data base redifinition according to the following categories:

 (1) Environment set header definition
 (2) Face and Light color tables
 (3) Light control parameter
 (4) Light size curve definition
 (5) Object and model definitions by coordinate system

d. The multifile structured data base is ideally suited for future extensions wherein different data retrieval, motion and priority processing algorithms might be required for different types of data bases. For example, two data bases with significantly different types and concentrations of scene detail, moving model and viewpoint motion characteristics might require different software algorithms for data retrieval, motion calculations and priority determinations. Such data base related software algorithms could be stored on disk files and initiated in conjunction with selection of the associated data base.

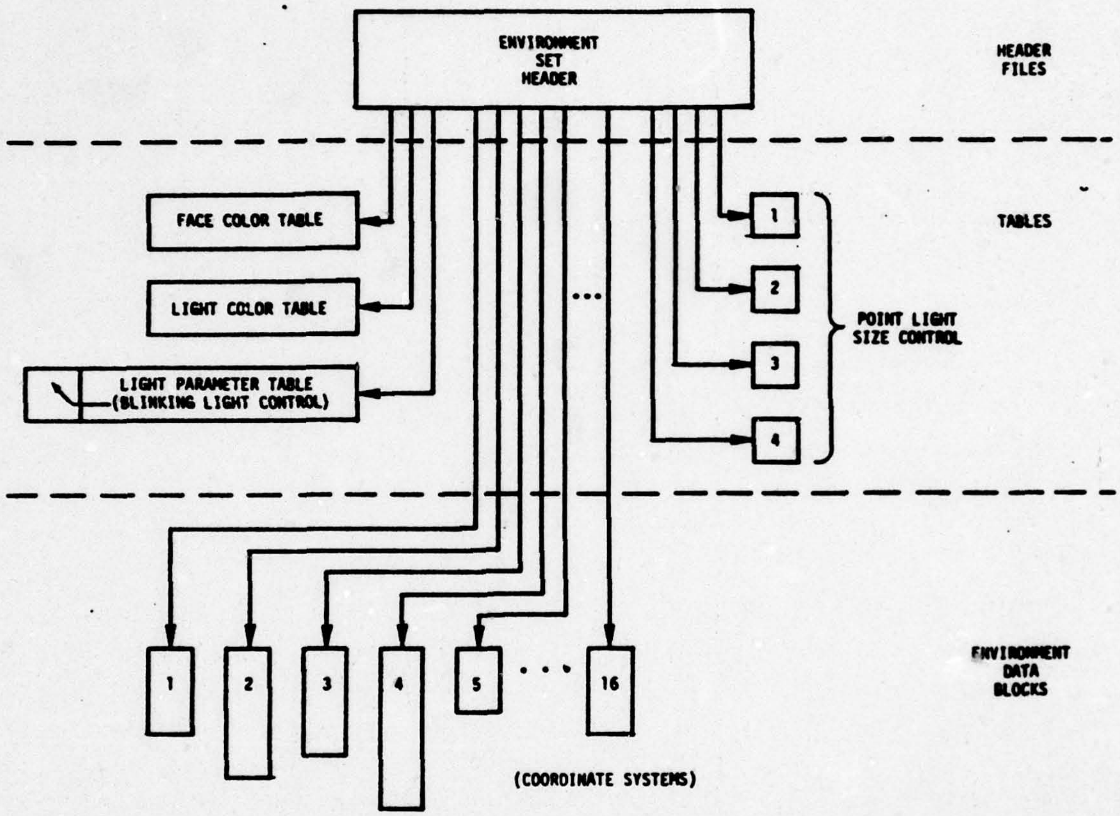


Figure 25. AWAVS Data Base Structure

e. **The fact that the new data base files are stored according to RSX-11M files format allows the user to maintain substantially improved configuration control in an area where daily changes can become a common occurrence.**